Politecnico di Milano

SCHOOL OF INDUSTRIAL AND INFORMATION ENGINEERING

Master of Science – Electronics Engineering

Design of Constant Power Supply for curing system

Supervisor

Prof. Franco Zappa

Candidate

Nadiya Zogh – 897924

Academic Year 2020 – 2021

Table of contents

List of Figures

List of Tables

I would like to acknowledge and give my warmest thanks to my supervisor Professor Franco Zappa, who made this work possible. His guidance and advice carried me through all the stages of writing my project. I would also like to thank my committee members for letting my defense be an enjoyable moment, and for your brilliant comments and suggestions, thanks to you.

Finally, I must express my very profound gratitude to my family and to my friend Babar Ali for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

1. Organic electronic

Organic electronic is a branch of electronics that makes circuits and other electronic devices out of organic materials, which have an advantage over the inorganic materials we're all familiar with. It's a recent development, but the possibilities are endless, and it's already accomplished a lot.

Organic electronics research has flourished in recent years as a result of its pledge to promote the production of products that can replace silicon-based applications with novel functionalities that silicon technologies cannot handle. When silicon is no longer cost-effective, plastic electronics can be used instead in applications with low performance requirements (e.g. tens of kHz). Organic semiconductors have the potential to revolutionize the industry due to their low processing complexity, compatibility with a wide variety of substrates, and chemical tunability. The almost limitless array of organic compounds opens up the possibility of tailoring materials to have any desired characteristics [1]. Flexible displays, electronic journals, sensors, disposable or wearable electronics, and medical applications are all possible applications for organic-based applications. Organic field-effect transistors (OFETs), organic photovoltaics (OPVs), organic light-emitting diodes (OLEDs), and sensors are all generating a lot of interest in academia and industry [1]. The field-effect mobility (μ) of charge carriers in the semiconductor layer is an important parameter in device activity. For example, in OFETs, is the figure of merit for system efficiency, with high mobility required to improve operational speed. Mobility is a complicated property that is influenced by the organic semiconductor's molecular structure and microstructure, as well as the consistency of contacts, interfaces, and other intrinsic and extrinsic influences. As a result of improved awareness of the factors that control transport in organic materials and devices, the highest recorded mobilities for organic semiconductors have increased five orders of magnitude in the last 25 years. Despite this impressive development, mobility remains low (1–10 cm2/Vs) and current state-of-the-art output is limited to low operation frequencies, with 1 MHz being the highest recorded [1].

Organic electronics started in the 1950s, when H. Inokuchi and colleagues discovered the first conducting organic molecule. This observation led to the conclusion that organic molecules would act as semi-conductors, a concept previously reserved for silicon, germanium, and other similar elements. Organic semiconductors, it points out, have many benefits over conventional semiconductors. Organic molecules can emit light, as discovered by W. Helfrich and W.G. Schneider, and this was first observed in the molecule called anthracene. The only drawback was that it needed a high voltage, making it inefficient. Then, in the 1980s, three scientists named Heeger, MacDiarmid, and Shirakawa discovered conductive polymers and were awarded the Nobel Prize in 2000 for their work.

To summarize, organic technology trades in performances (especially carrier mobility) for ease of processing. The processability from solution, or better the possibility of formulating organic semiconductors as functional inks, opens the possibility of adopting deposition techniques traditionally used in the graphic arts, such as inkjet-, aerosol-, gravure-printing, xerography to cite but a few [2]. Organic electronics transforms into printed electronics as a result of these methods, allowing it to address large (and not inherently flat) areas, heading in the opposite direction of silicon electronics, which has historically been powered by miniaturization. Finally, because of the powerful versatility of synthetic chemistry, another feature of organic electronics is the ability to choose, alter, and tailor materials in terms of their physical and optoelectronic properties [2].

Organic electronics have found their way from basic academic research to industrial applications over recent years in a quickly growing market. This market covers especially application fields in light-emitting diodes (LEDs) field-effect transistors (FETs) and solar cells which open the window for a novel type of technologies. The main element is the semiconducting, conjugated organic materials, which can be processed into devices from solution, allowing large area and low-cost fabrication [3]. Moreover, many organic semiconductors are mechanically flexible and therefore applicable to bendable electronic elements. The mass fabrication of the devices occurs by high-speed and inexpensive methods at low temperatures and is realized by well-known continuous in-line roll-to-roll technologies, such as inkjet, offset, rotary screen printing and others, which are adapted to the specific requirements of the organic materials [3]. Due to the low-cost processing, one-way applications of electronic elements are realizable such as radio-frequency identification (RFID) tags and sensors in which FETs play a major role. Thereby, the performance of a transistor is mainly determined by the speed of the charge carrier transport from one electrode to the other, which in turn depends on various factors such as molecular design, supramolecular organization, thin film microstructure and charge carrier transport.

These products have a lot of potential for mass production. Rapid roll-to-roll techniques usually result in poorly arranged films on the substrate surface, resulting in mobilities that are at least two orders of magnitude lower than those obtained in the lab for most organic semiconductors [3]. This problem could be solved by using polymers with less order-based system output. To ensure an identical device performance after mass production, new processing approaches are required which can induce a higher molecular order on the meso- and macroscopic scale, or alternatively orient the molecules in the desired direction of charge carrier transport.

1.1 Organic Photovoltaic (OPV)

Organic photovoltaic systems are usually solar cells made of organic materials. Typically, polymers are used as photovoltaic materials. One of the main advantages of using organic material for solar cell manufacture is that the ‘optical absorption coefficient’ of organic molecules is high, so a large amount of light can be absorbed with a small amount of material, usually on the order of hundreds of nanometers [4]. They are also very flexible and much thinner than their silicon counterparts. While current OPV (Organic Photovoltaic) technology boasts conversion efficiencies that exceed 10 percent, reaching even 12 percent, some researchers predict organic solar cells will reach 15–20 percent efficiency [4]. They can be rolled up and composted as well.

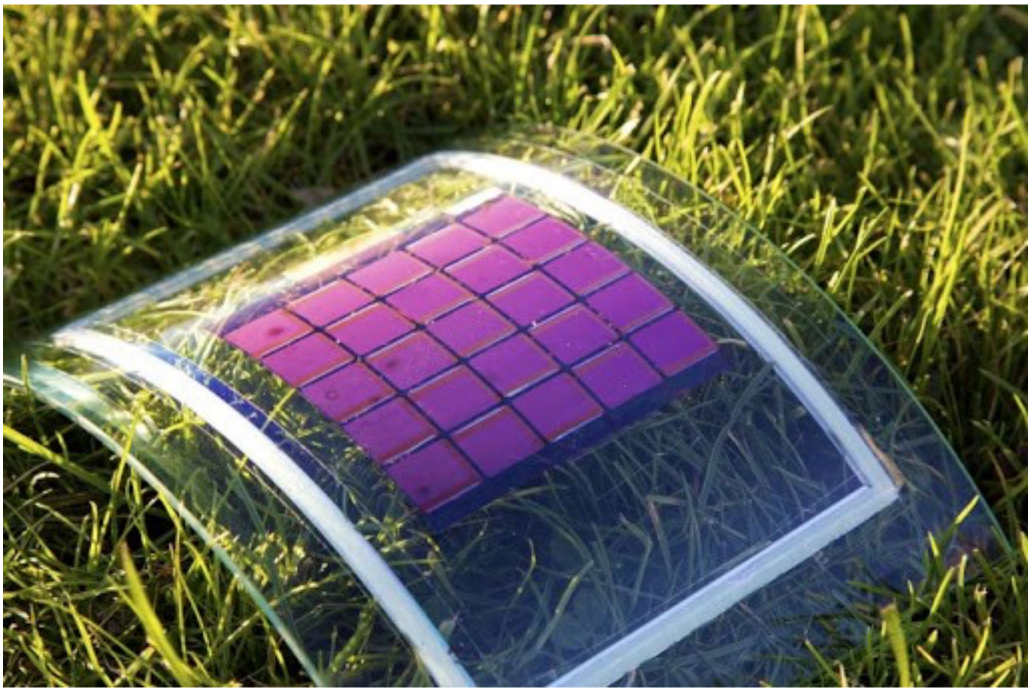


Figure 1-1: the future of solar cell-OPV

1.2 Printed electronic (PE)

Printed electronics (PE) is the method of depositing functional materials on a substrate in order to create electronic circuits, interconnects, electrical components, or devices. This methodology is opposite to the conventional microelectronics industry which is based on subtractive manufacturing techniques (e.g. etching). Some of the advantages of PE over conventional electronics are low prototyping costs, short time to market, less processing steps, etc [5]. The ability to create flexible and customizable products and devices is one of the benefits. Printed Electronics can be used in a number of industries, including electronics, packaging, biomedical, automotive, and communication.

Whilst organic photovoltaic (OPV) efficiencies have exceeded 14% in research [6], the majority of proposed systems are small-scale devices manufactured using spin coating - which wastes large amounts of materials and is a batch processing technique . Less costly approaches that are consistent with continuous processes must be used to produce these cells on a large scale. Coating techniques, which are suitable for lab-scale to large-scale manufacturing, and printing techniques, which are commonly adapted from large-scale commercial processes, can be broadly divided.

1.3 Printing technique

Because of the low cost of fabrication and the prospect of obtaining multifunctional electronics over wide areas, printing sensors and electronics on flexible substrates is a significant topic. A variety of printing technologies have been developed over the years to pattern a wide range of electronic materials on a variety of substrates [7]. Since printed technologies for sensors and electronics are expected to expand in the future [5], it is important to review the common features, complementarities, and challenges associated with various printing technologies.

Critical challenges in various printing techniques and potential research directions have been highlighted [7]. To expand the lab-developed standalone systems to high-speed roll-to-roll production lines for system level integration, the possibilities of integrating various printing methodologies have been explored.

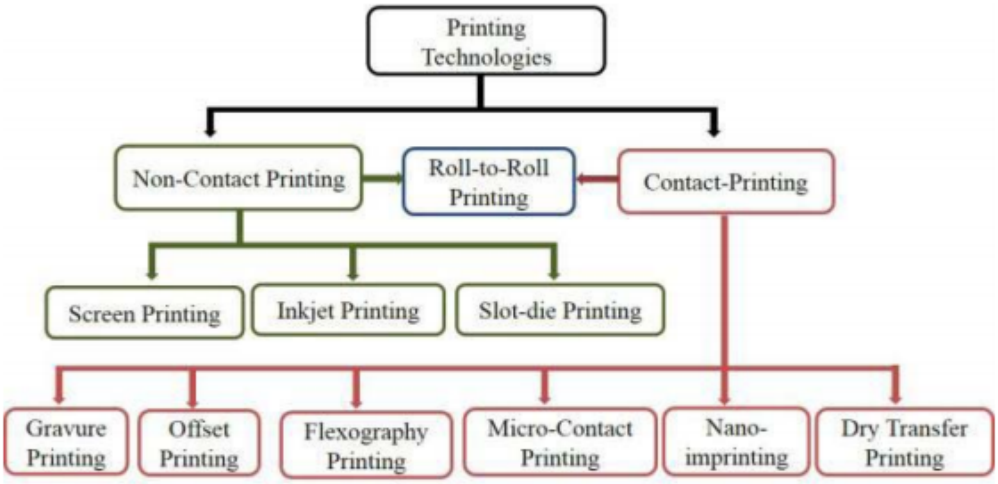


Figure 1-2: The classification of common printing technologies

The patterned structures with inked surfaces are brought into physical contact with the substrate in the contact printing process [7]. The solution is dispensed through openings or nozzles in a non-contact process, and structures are established by moving the stage (substrate holder) in a pre-programmed pattern. Gravure printing, gravure-offset printing, flexographic printing, and R2R printing are all contact-based printing technologies. Screen printing, slot-die coating, and inkjet printing are some of the most popular non-contact printing techniques. Non-contact printing techniques have gained popularity due to their distinct advantages, which include flexibility, affordability, speed, adaptability to the fabrication process, reduced material waste, high pattern resolution, and ease of control by changing a few process parameters.

Here we will talk about four important techniques [8].

- Gravure printing
- Flexographic printing
- Screen printing
- Rotary screen printing

1.3.1 Gravure printing

Gravure printing requires the physical interaction of engraved structures with the substrate, resulting in direct transfer of functional inks. It is capable of producing high quality patterns in a cost-effective manner typical of a R2R process [7]. The gravure printing tools consist of a large cylinder electroplated with copper and engraved with micro cells, as shown in Figure below. The microcells are engraved either by using electromechanical means or using laser.

The lack of printing lines with high resolution, i.e. less than 20 m, is a major challenge for gravure printers. Gravure printing's ability to create uniform structures with sharp edge pattern lines limits its application to the fabrication of such layers in electronic devices that do not need high-resolution patterns. Gravure printing has thus been used to produce organic flexible LEDs and photovoltaic devices. The expense of sustaining printing technology is increased by the regular replacement of gravure cylinders after continuous use in a roll-to-roll (R2R) method. Achieving the goals of getting small channel lengths, enhancing printing resolution with proper circuits design in order to avoid parasitic capacitances and gate overlaps are restricted by the limitations of the existing technology.

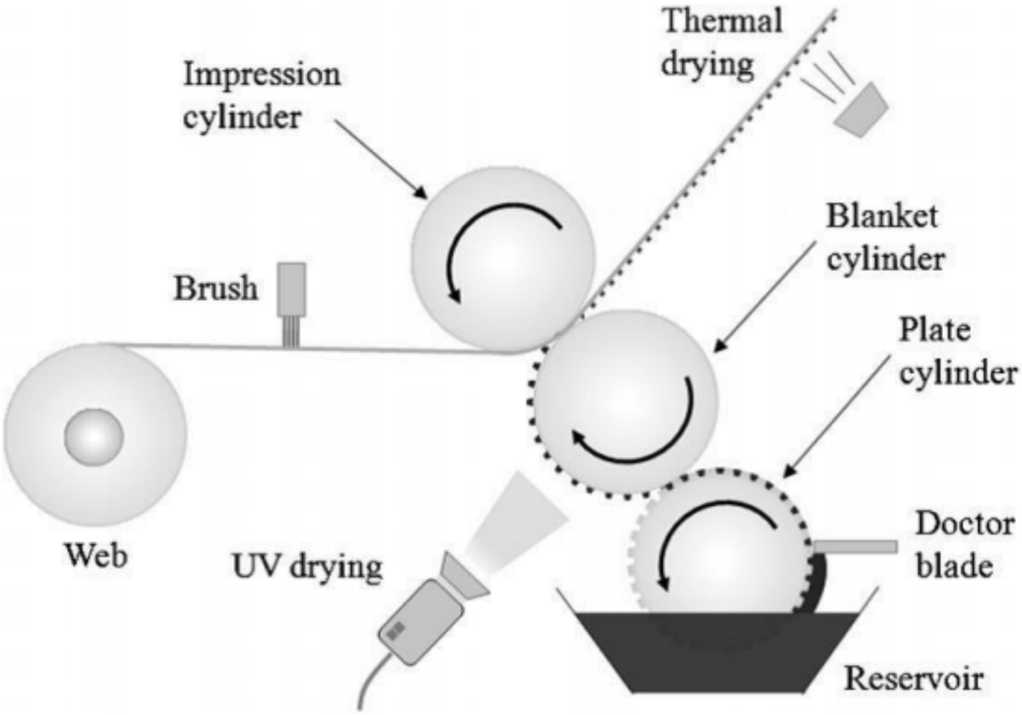


Figure 1-3: Schematic of typical micro-gravure-offset printing process [7]

1.3.2 Flexo-graphic printing

We print our labels using the flexographic (flexo) process. Our cutting-edge flexo presses are suitable for high-volume, high-quality printing [8].

Flexographic printing is an R2R technique that differs from gravure printing specifically in that ink is transferred from a relief rather than cavities. The final pattern stands out from the printing plate which is typically made from rubber or a photopolymer. Fountain rollers continuously pass ink to the ceramic anilox roller, which has etched cells/micro cavities embedded into the exterior, in the flexo system. This allows the collection of ink which is then transferred to the relief on the printing cylinder that performs the final transfer to the web. As shown in figure 1-

5, the ink pick out from the anilox corresponding to the negative pattern of the motif can be seen directly. Roll-to-roll flexographic printing is a relatively new technology for organic solar cells and has so far not been used for direct processing of the active layer, but examples of its use include the processing of modified PEDOT:PSS, processing of a wetting agent on the surface of the active layer, and the patterning of conductive grids (roll-to-roll) with a line width below 50 µm, which could potentially be used as electrode structures for ITO-free organic solar cells.

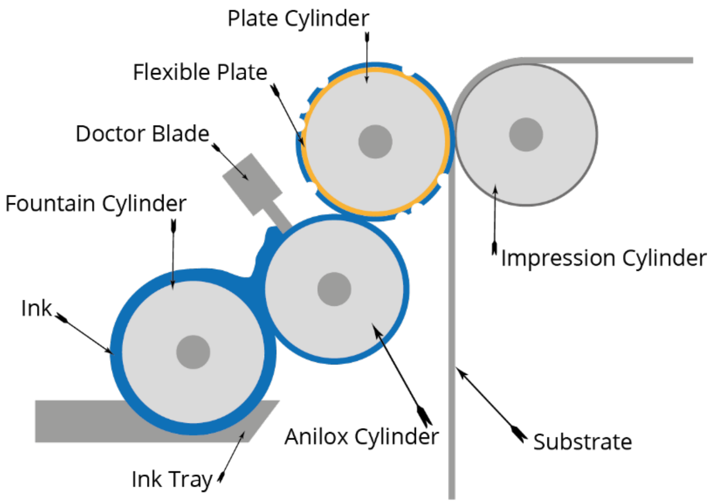


Figure 1-4: Flexo-graphic printing

1.3.3 Screen printing

Screen printing is the most widely used and well-established printed electronics technique, having been used in the electronics industry for many years to print metallic interconnects on printed circuit boards. It adds simplicity, affordability, speed, and adaptability to the fabrication process, making it faster and more flexible than other printing tools [9]. Screen-printing results can be reproduced by repeating a few steps, and an ideal operating envelope can be quickly created.

For R2R manufacturing, two separate screen printer assemblies, flatbed and rotary, are used, as shown in Fig. 1-6 (a-b). Screen printer has simple setup comprising of screen, squeegee, press bed, and substrate, as shown in Fig. 1-6. The ink poured on the screen is squeegeed over the screen [10], allowing it to pass to the substrate beneath it through the stencil openings. Flat bed screen printing is a versatile method for small laboratory systems for optimizing materials and processing steps. For continuous processing, flatbed screens can be replaced with rotary screens, in which the web of the screen is folded while the squeegee and ink are mounted within the tube.

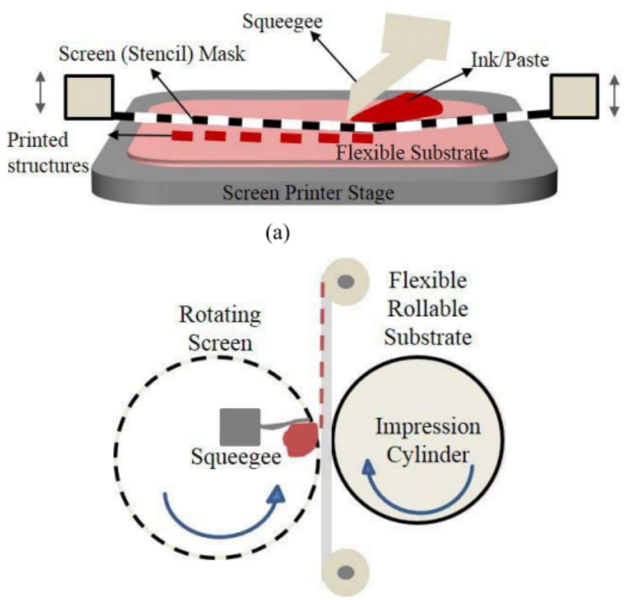


Figure 1-5: Flatbed screen printing and rotatory screen printing

As it shows in figure 1-7, flat-bed screen printing of silver paster showing the squeegee after passage over the motif (left) and the squeegee during a printing cycle showing how the ink is forced through [11]. The printed motif can be seen in the lower part of the image (middle). A photograph of rotatory screen printing of conducting graphite ink onto a clear polyester foil (right).

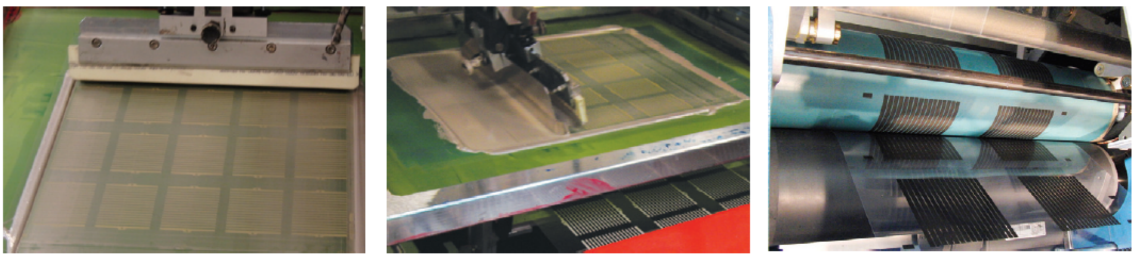


Figure 1-6 Flat-bed screen printing

1.4 Drying and advanced processing post-film formation

The most popular post-film formation processing technique is drying the wet film. This has traditionally been accomplished by heating a wet film to remove the solvents and leave a dry film of the desired material [8]. Even though it is not a dry ink, UV-curing has recently been introduced for many adhesive systems as a solvent-free ink alternative (at least not until it is fully cured). Drying and curing are complex processes that warrant a review of their own, but to give an example the very common process of hot air drying and UV curing have also been applied for screen printed silver back electrodes in inverted type OPVs. The power conversion efficiency of several different silver inks was compared, and it was discovered that the only UV curable ink tested had the highest PCE. A later study using light beam induced current (LBIC) measurements concluded that the solvent-based silver inks degraded the current production in the adjoining active layer while this was not the case for the UV curable ink and nor was it for a specially developed water-based thermally curing ink [8]. Another example is the use of an intense source of light to thermocleave polymer side chains in an OPV R2R coating process. Using an oven set at 140 °C to thermocleave a polymer required four hours, making this an impractically slow process while using a custom build lamp with narrow wavelength high intensity (Fig. 1-8) enabled much faster web speeds of 0.2 – 0.4 m/min.

With the introduction of lasers capable of delivering ultra-short pulses (pico- to femtosecond), new possibilities of performing selective laser patterning have emerged with potential use in R2R processed organic solar cells. Due to the short pulse duration, very little heat is generated and it is thus possible to selectively remove a thin layer without destroying what is beneath. Initial reports related to solar cells have primarily been focused on the patterning of ITO on glass and PET. So far the technology has yet to prove that functioning laser patterned solar cells can be produced, and cost-wise the concept of removing applied material is generally not a preferred pathway in production if it can be avoided, but it has the potential to be a useful tool for niche productions.

One distinct benefit is that it can be used for scribing, which could be useful in future OPV modules with large geometric fill factors. Using slot-die coating and screen printing, geometric fill factors of 45–67% [11] can currently be achieved. This can be raised to about 85% with great precision, but it is unlikely to be taken any further.

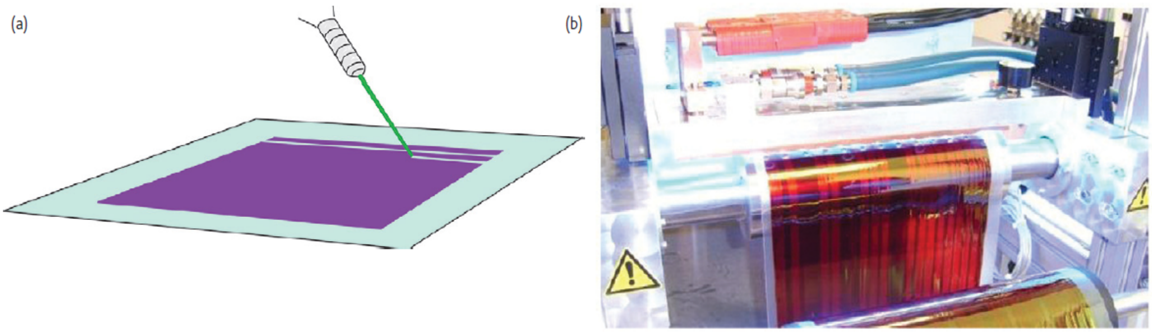


Figure 1-7 (a) schematic drawing of patterning of the layers post-processing and (b) the use of intense light with a specific wavelength or pulse length to selectively address for instance the active layer

1.5 Lamination

For many factors, after the entire solar cell stack has been printed, it must be encapsulated on the printed side. The most important reason is operational stability [8]. Mechanical protection of the delicately printed layer stack during processing and handling is another nearly equally essential consideration. Lamination is a simple method that can be done in a variety of ways with simple equipment, all of which follow the same basic concept of joining two lines of web by applying pressure as they are fed between two rollers. Cold lamination uses a pressure-sensitive adhesive that is lined and added to the laminate by a lamination process, then the liner is removed and the solar cell stack is laminated. This is very simple and easy to control at the laboratory level at high speeds (> 20 m min-1 is easily accessible). The same idea applies to hot melt lamination, except that the laminate already contains an adhesive substance that becomes adhesive when heated [12]. The laminate and the solar cell substrate are then forced together between heated rollers, allowing the adhesive to melt and create a tight seal. Until putting the two foils together, UV lamination necessitates the application of an uncured adhesive or glue by printing or coating. In the laminator, the glue is cured by the application of UV-light. In terms of operation, hot-melt is by far the easiest with cold lamination being slightly more complicated because one has to handle sticky adhesive and this implies that only one side of the foil can be handled (the non-sticky one). UV-lamination is the most difficult because it requires a printing or coating step. UV-curing adhesives are commonly printed using flexographic printing. There are some limitations to cold lamination [13] in terms of adhesive thickness, with usually 50 microns of adhesive being easily treated. It is possible to employ pressure-sensitive adhesives as thin as 20 microns, but it does present some challenges and the major drawback of cold lamination is the relatively thick adhesive layers that must be employed. Hot lamination on the other hand enables very thin adhesives to be employed and this may be an advantage in some cases but can present problems if the surface topography of the solar cells is rough (i.e., for a screen printed grid with a thickness of 5 – 20 microns). UV-lamination allows for the widest variety of adhesive thicknesses and is limited only by the printing method used and the adhesive's curability. (1 – 100 microns is achievable) [11]. Figure 1-9 illustrates the relative similarity of the various roll-to-roll lamination techniques.

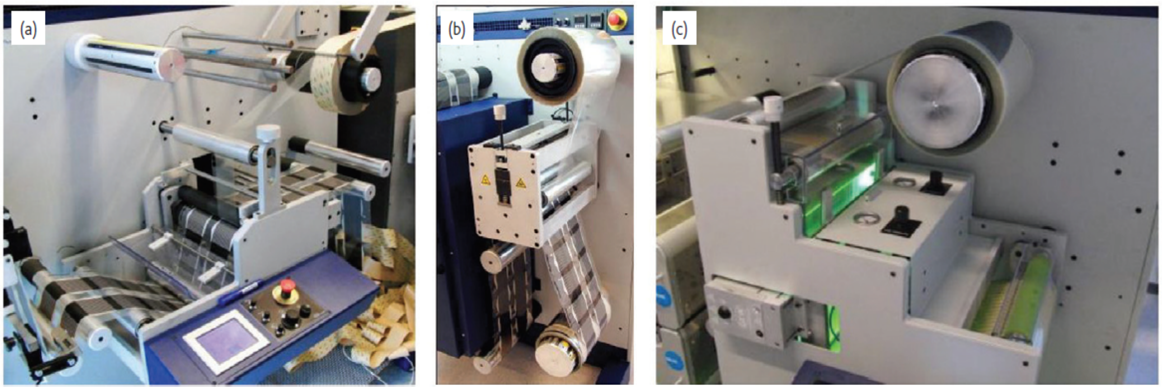


Figure 1-8 Photographs of cold, hot melt, and UV-Lamination station

1.6 Device integration and application

The final step in the roll-to-roll manufacturing of OPVs is, of course, what happens after production and testing. TThere haven't been several well-documented examples of OPV integration, application, or demonstration, and this is obviously a separate subject that will develop over time as OPV technology becomes more widely accessible. Before the polymer solar cell technology can be fully used, device or product integration must either be achieved using a roll-to-roll technique, or at least a technique that enables the OPV to join the process on a roll. Otherwise, the big advantage of roll-to-roll technology would be lost.

1.7 Summery and outlook

Roll-to-roll production will certainly be at the core of OPVs in the future, and the efficient realization of low-cost OPVs will be inextricably related to this. However, there are other criteria, and roll-to-roll processing and methodologies are just one aspect of a larger equation. Aside from efficient production, effective process management during manufacturing is required, and new materials and processes are urgently required. The printing of semitransparent electrodes and complete processes designed to allow complete fabrication of efficient solar cells are among the most important materials and processes. The materials and processes should of course give access to OPVs that provide operational stability of > 10 years and they should be efficient (> 10 %). To achieve a low embodied energy, the OPV must have as thin an outline as possible by using as few materials as possible. The manufacturing should not be harmful to the environment, and it should need very low input energy for manufacture by using the lowest temperatures possible. This, taken together, will enable short energy payback times, and < 10 days should be possible. Manufacture of the entire solar cell stack at an overall speed of > 10 m min^{-1} will enable the manufacture of a daily energy production capacity of more than 1 GWpeak and thus, in principle, fully address man-kinds future energy needs.

1.8 Roll-to-roll fabrication of polymer solar cell

As the performance in terms of power conversion efficiency and operational stability for polymer and organic solar cells is rapidly approaching the key 10-10 targets (10 % efficiency and 10 years of stability) [8] the quest for efficient, scalable, and rational processing methods has begun. The 10-10 targets are being achieved through consistent laboratory research activities, which, when combined with early commercial efforts, have resulted in a fast-paced research field and the development of a new industry. We go through the roll-to-roll processing techniques that are needed to make the magnificent 10-10 targets a reality, using fast, low-impact, and low-cost methods.

Solution processing, low cost, low energy budget, flexible solar cells, are keywords associated with organic solar cells, and through several decades the driving force for research within the field of polymer solar cells has been the huge potential of the technology to enable high throughput production of cheap solar cells. Small area cells were the first to be created, using simple and relatively inexpensive fabrication techniques such as spin coating and thermal evaporation. The unstable nature of conjugated polymers when illuminated in the presence of oxygen and the reactive nature of low work function metals such as calcium towards water quickly led to the preparation of organic photovoltaic (OPV) devices in the protective atmosphere of a glove box. The key motivation was to increase power conversion efficiencies to meaningful levels in the sense of global energy supply [11].

Claims of meeting these goals have now been made for small area solar cells (a few mm^2 to around 1 cm^2) with efficiencies reaching 8 – 9 % [11] but the field of organic solar cells is now facing the huge challenge of returning focus towards the original goal of large-area production using a high throughput process. Such a shift in methodology does not automatically appear. Spin coating and high vacuum thermal evaporation are not consistent with high throughput output, which should ideally be done in a continuous process such as roll-to-roll (R2R) processing.

As a consequence of both the economical aspect of acquiring and running the necessary machinery and the focus on high efficiencies, the number of participants working with large-area solar cells in true roll-to-roll coating processes has previously been limited. It should also be highlighted that the power conversion efficiency is considerably lower for larger area devices (currently < 3.5 %) [14]. For the organic solar cell to succeed as a technology, more effort must be directed towards large-area fabrication combined with high throughput processing such as roll-to-roll methods.

We review some of the different printing and coating techniques that are fully compatible with R2R processing, and which could potentially be used in future mass production.

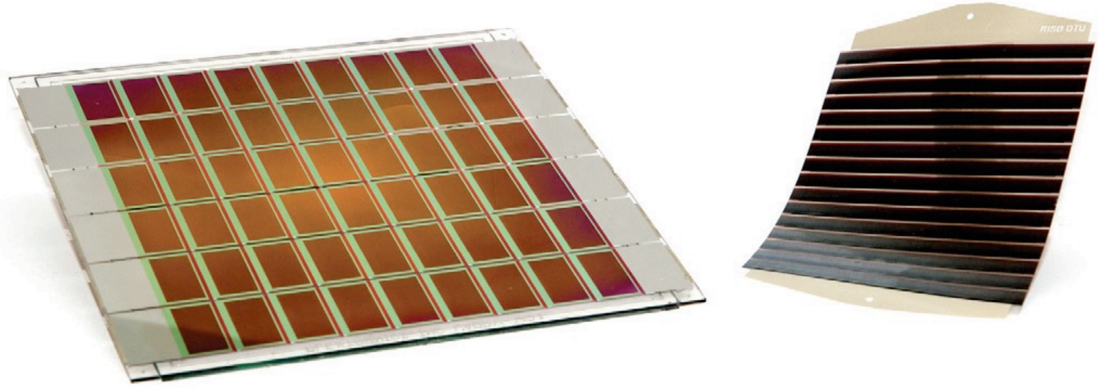


Figure 1-9 An illustration of possibly the most refined example of an OPV module prepared using the laboratory route, comprising a rigid glass substrate, spin coating, metal evaporation, getter materials, and a glass seal with a thick outline of several millimeters

For polymer and organic solar cells, the possibility of solution processing has overturned this picture, and the wide selection of printing and coating techniques available may end up being what defines polymer solar cell technology. When looking at OPVs as a technology it is important to consider our current position, which is in the doorway between the controlled and safe laboratory environment (behind us) and the outside world and field of application (in front of us).

As our premise, we have the spin coating technique and the solution-processed laboratory device. We desire to find the right combination of techniques that will yield the same result albeit on a larger scale, by a factor of > 1 000 000 in terms of both processed area and processing time (and several other parameters).

2. Roll-to-roll UV curing

1.9 Introduction

The demand for new applications such as e-paper, smart sensor arrays, smart cards, signage, and flexible displays is driving the market for flexible electronic applications. Flexible electronics display has many advantages for customers, which include cost reduction, improved robustness, bendable properties, and lower power consumption. The flexible electronics market is expected to expand to the same extent as the current Si electronics market. At the current time, several plastic electronic applications need micron-sized patterns on 25– 100 lm thick foil (typically PEN, PET or PEEK) [14]. Applications include flexible displays, rollable displays, lab-on-chip, etc. Processing foil, as opposed to *Si*, faces challenges, such as low dimensional stability because of humidity, temperature environment and handling, a higher roughness, and continuous processing. Roll-to-roll (R2R) UV imprint/embossing, we assume, will solve these issues and prove to be a reliable solution for a variety of applications. Because embossing/imprint is a contact technique, no focusing is needed as in optical lithography. Moreover, the roll-to-roll (R2R) processing allows a higher throughput than in stand-alone lithography. Finally, high resolution and 3D patterning are possible. R2R embossing is a technology widely introduced in several so-called single-layer applications, like surface texturing for light management (Organic Light Emitting Diode OLED and organic photovoltaic), photonic structures, lab-on-chip [14]. We also believe that R2R embossing might be a low-cost solution for transistor patterning. By implementing self-aligned concepts, the challenge of overlay through consecutive imprint steps is avoided.

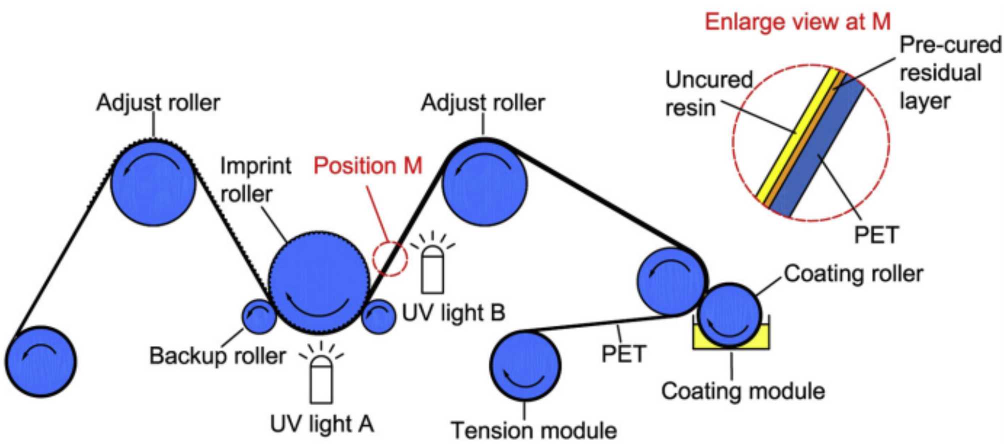


Figure 2-1 Schematic diagram of the roll-to-roll UV imprint lithography system [14]

In recent years, traditional mercury arc lamps have shown a number of drawbacks, most notably for the environment. They emit ozone and need exhaust systems to avoid contaminating the air. These UV curing systems often consume a lot of energy and generate a lot of heat while they're in use. They often require the use of mercury, which has a long-term environmental effect, as previously stated.

UV LED curing provides all of the advantages of conventional curing while still resolving the negative environmental effects. This new technology decreases heat radiation while offering instant on/off switching. UV LED curing also reduces the need for moving parts. All of this leads to a decrease in the amount of energy required [15].

Aside from the environmental advantages, LED UV printing enables printers to use a variety of heat-sensitive substrates and create unique and artistic effects. It also provides increased productivity because of how quickly and effectively it cures liquid UV Chemistry.

UV LED curing also has plenty of other advantages, including: [15]

- Increased Efficiency
- Ensured Safety
- Environmentally Friendly
- Long Life Service
- High-End Functionality
- Well-Suited for Heat-Sensitive Substrates
- UV LED Curing Applications

Although traditional UV curing has been used for decades, modern UV LED curing technology is rapidly replacing it in many of its popular applications. UV LED curing is used in a wide range of applications, including adhesives, coatings, and printing inks. This method is suitable for any application that necessitates fast and efficient curing, as well as increased system capabilities and environmental benefits.

Many of today's coatings, from flooring and cabinetry to advanced electronics, are cured using UV LED curing technology. It's applicable to any industry that uses inks, varnishes, silicones, coatings, or adhesives. As this new technology is introduced into the workplace, the number of industries and applications continues to grow.

In addition to these uses, the process can also be found in: [15]

- Medical Device Manufacturing
- Decorating
- Stereolithography
- Electronics
- Food Packaging

- Graphic Arts

The ultimate aim of the above technologies is to combine different printing schemes to create a quick and effective production line. Better performance is obtained in highly optimized laboratory processes by establishing a close relationship between the processing methods, materials, solvents, substrates, and drying conditions. Printing processes that have been perfected in the lab must be moved to large-scale, high-speed production lines with the same degree of quality [7]. Merging different printing techniques into a single production line is rather a challenging task, as very precise control of the process and material parameters need to be tuned especially when the substrate is moving at very high speeds as 5-50m/min.

R2R as a commonly shared platform has the potential for a continuous and high throughput process for deposition of diverse materials on large substrate rolls (often called "web").

R2R fabrication is more attractive for organic/polymer-based thin film devices and has been explored extensively for solar cells, organic/polymer light-emitting diodes, and display devices. Besides these applications, the focus is also on the development of sensory devices and patterned structures, which has become possible due to the rapid development of stable R2R systems with more patterning tools. For large-scale production, these printing technologies must be scaled or combined on R2R production lines without losing the device's chemical, physical, or electrical characteristic. The large area of electronics through R2R production lines is foreseen to play a major role in the cost-effective manufacturing of nonconventional electronic devices and systems.

1.10 UV led curing system

UV curing is a photopolymerization process that turns a liquid into a solid by using UV (ultraviolet light) energy. With the absorption of the UV energy, the photoinitiators contained in varnish, ink, adhesive, or resin in the liquid state produce substances called free radicals, that react with the chemical compounds of the liquid substance, turning it into solid. This process is also called "polymerization" [16].

For several years, quartz discharge lamps have been used in the conventional UV curing process; they contain mercury and sometimes other substances known as halides [16]. These improve the UV emission at certain frequencies (nm) where photoinitiators react better.

The beginning of the third millennium marked a technological change of light sources commonly used in visible lighting (home, public and industrial sectors) and UV light.

An LED is an electronic component, also known as a diode, that is created by a p-n junction in a semiconductor material. Depending on the type of semiconductor material used, the junction emits visible light, infrared, or UV radiation when a certain electric current is applied to its ends in a forward direction.

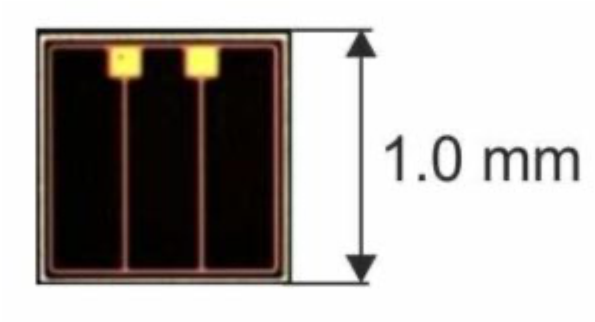


Figure 2-2 Typical image of a bare LED UV [16]

Among the sources of UV light, UV LED represents the future, offering many advantages in curing and drying industrial processes.

The production of LED UV systems is a complex process as it involves very high know-how in microelectronics, optics, and thermodynamics, to get technologically advanced results and high quality and efficient products.

Photo Electronics for many years has been investing resources in this field and today offers the complete range of DROLED UV LED lamps with excellent characteristics and expected long life, among all the lamps currently available on the market.

1.10.1 Application advantages

- Low heat generation [17]
- Instant switching on and off
- Modular power 0-100%
- Width of partializable irradiance
- Contained sizes that permit easy integration in the production machines.
- The possibility of end-to-end scalability of lamps achieved a continued irradiance.

1.11 The benefit of UV cures system for printing

UV cure primers, inks, and coatings are commonly used in printing processes and provide advantages that other technologies cannot reach. UV cure systems offer a high speed, quick-dry (cure), low energy, and environmentally friendly solution for all commonly used print methods – lithographic (offset), flexographic, screen, gravure, and inkjet. Instead of drying ovens, UV cure is based on the use of ultraviolet (UV) light to initiate a photochemical reaction that crosslinks the polymers providing an instantly dried system that is immediately ready for further handling. This fast drying time improves printing results by giving dust and airborne impurities no time to contaminate the print surface.

UV cure systems for printing do not rely on solvent for viscosity reduction and so there are no solvents to evaporate during the process resulting in virtually no VOC emissions and no coating thickness or volume loss. UV cure systems have a consistent and reliable finished print surface while also increasing efficiency and reducing energy consumption, waste, and emissions.

Besides inks, primers and overprint varnishes (OPVs) can be applied and cured as part of UV curable print systems. Primers act to standardize the print surface for performance and appearance to accept the subsequent ink application. OPVs provide a protective and aesthetic layer over the inks. With UV technology, a high gloss surface can be immediately achieved without the need for any further steps. Additionally, though, the OPV can be formulated to provide other aesthetically unique appearances that make the finished print surface stand out.

The high-performance curing system LED powerline Flexo was specially designed for curing highly reactive inks in flexo printing applications [18]. The LED curing unit has got a maximum output of > 25 W/cm^2. According to the application, it is supplied as an air-cooled or a water-cooled version.

UV-/LED-Hybrid is based on the water-cooled version. The unit can be used as a conventional UV or a LED-UV curing device just by an easy and fast-changing cartridge. The control unit immediately recognizes the type of technology equipped and automatically changes all parameters [18].

1.12 Label converting

Ingredients, correct usage and storage, and safety warnings are all communicated on product labels. They recognize brand names, trademarks, and logos; provide decoration; attract potential customers' attention; give chances to win a contest, inspire buyers to buy; and even provide guidance about how to properly dispose of or recycle the item or packaging when finished.

In label converting, manufacturers around the world rely on UV-cured inks, coatings, and adhesives to create highly decorative, durable, and functional product labels that exhibit significantly brighter and bolder colors than water- or solvent-borne formulations. Labels are often filmed Laminated with an IN curable adhesive, further protected with an IN curable matte or gloss varnish, and ultimately applied to a wide range of consumer and industrial goods and packaging. When brand managers want their products to stand out from the competition, UV-cured labels are needed.

1.13 Benefits of UV LED

Faster curing – UV LED industry-leading dose output supports the marker's fastest printing speeds.

Print without limitations - Unsupported films, shrink sleeves and other delicate materials can be processed without heat damage [19].

Reduced energy consumption - Higher electrical efficiency of LEDs and instant on/off switching allow typical energy savings over 50% (versus a brand new UV Arc system) [19].

Increased machine uptime - No moving parts for low maintenance and no warm-up/cool-down means less UV-related downtime = better press productivity [19].

Longest LED warranty - UV LEDs are designed to last 20.000 hours. Offers up to 3 years warranty irrespective of running hours [19].

No ozone, no mercury – UV LEDs produce no ozone. so there are no air extraction requirements [19].

1.14 Comparison of UV LED versus UV Arc in roll to roll production

Traditional UV arc lamps produce UV energy by generating an electric arc inside an ionized gas (typically

mercury) chamber to excite atoms, which then decay and emit photons. The emitted photons cover a broad range of the electromagnetic spectrum, including some infrared and even visible

light as shown in Figure 1. Only about 25% is in the safer UV-A range. A UV-LED generates UV energy in an entirely different way. As an electric current (or electrons) move through a semiconductor device called a diode, it emits energy in the form of photons. The specific materials in the diode determine the wavelengths of these photons and, in the case of UV-LEDs, the output is typically in a very narrow band +/- 20 nm. The wavelength is dependent on the band gap between excited state and the ground state of the semiconductor material. The chart in Figure 1 compares the output of a 395 nm, UV-LED lamp with a typical mercuryarc lamp. It is important to note the difference in intensity and wavelength of the output as both are key to understanding a UV-curing process.

3. Constant power supply

This chapter is related to the construction of a Constant Power Supply system for a smart curing system as a part of the I-label project. The purpose of the research and development of this project is to find a unit to stabilize or make a constant input power supply, respect to the cable sizing and length switch protection.

Many manufacturing industries now include activities in hazardous conditions due to the presence of flammable or explosive chemicals.

The technology of drying inks is used in the packaging industry for printing labels with UV emitting sources, especially mercury lamps. In general, mercury gas tubes are used to produce UV rays, that are then irradiated at a high intensity directly above the plastic film (label) in a simple and effective manner.

It should also be noted that in these conditions, maintenance becomes extremely necessary for structures that can only be reached safely by allowing for a prolonged shutdown of the production plants, as well as waiting for the full shutdown of the UV source.

Our project is based on the creation of a product that allows for the drying of prints using LED lamps rather than mercury lamps due to the high speed of switching on and off. On the other hand, since in the printing label, there is some position that must be printed and some position must be out of printing, by using LED we have the possibility in the position X-Y to emit the light. In comparison to a lamp, the most apparent advantage of LEDs is that they are an array. The advantage of an array is that if one diode fails, the surface light intensity is only slightly affected. On the other side, we can design a device that includes a line of LEDs that emit different wavelengths with feeding them by different constant current. LED lamps are also much more energy efficient; they only use around 20% of UV radiation for curing and only turn the other 80% into heat. Furthermore, LED lamps are risk-free in the workplace, whereas mercury lamps are dangerous. For example, there are no harmful effects if the outer shield of an LED array is broken, but if the outer bulb of a mercury lamp breaks, extreme UV radiation is released, which is harmful to health. LEDs are, in practice, much less costly than laser sources, but they are less directional. They necessitate a more complex optical device design that allows for optimal light radiation coupling above the plastic film.

The project that VDGLab intends to carry out has the potential to create a significant evolution of the entire label market by considering two related strategic objectives:

- Flexibility and efficiency of the solution: the project can be included as an application for which currently no commercial solutions exist due to technical or economic limitations.

- Reduction of the costs for the realization of the design solutions compared to the technologies which are used in today's market and customer demands:

One of the important aspects of the project is to create an extremely effective solution, using VDGLab's consolidated expertise in lighting design, optimization and control through LED sources.

Combining these technical and economic features has the potential to trigger a significant evolution of the market in this sector.

1.15 Introduction

These days, the development of a constant smart power supply and backup battery (backup) is needed to supply power to LED ultraviolet emitter systems for printing systems on plastic media. At DC output towards the load, a current generator circuit must be provided which will provide a constant intensity of current but with variable pulse length over time, according to the positioning of the printing matrix to be dried, arranged on a rotating drum in the curing system.

On the other hand, Due to the continuous repetition of UV flashes, we will have a peak, so matching the size of the power supply and the buffer battery is necessary for the maximum current.it means that the system requires oversizing of the cable and protections upstream of the circuits. If we choose a system suitable for peak it will be costly that's why we will design a capacitor and put it in the circuit to compensate for the peak and choose everything in common size, we have to notice that there is a possibility to increase the number of power supplies connected to the same line.

VDGLAB hypothesizes is to create a constant power circuit to protect the network so it will need a power supply with a storage system like a supercapacitor or large capacitors which are constantly charge and it provides the energy that is necessary for the flash generation which too is positioned inside the current control modules in the LEDs.

The current generator must emit pulses synchronized with the rotating drum to emit UV rays exactly in the position required in the X-Y axis; therefore, it is necessary to create a communication system, a shared protocol, with the management of the rotating drum motor.

Due to such designing of constant power supply, we started to do some steps for calculation:

1. Calculation of capacitance based on thermal performance and we found a suitable electrolytic capacitor for this project with the value of 22000uF and 100v.
2. Finding a suitable auxiliary to supply our PFC fly back.
3. Next step is related to designing PFC fly back in which we have to calculate the turn ratio for the transformer and test in the VDG laboratory and build the prototype of the transformer.

4. Designing the feedback for measuring power that includes measuring current, voltage, and power reference, hence we have some ideas that we must see which one is suitable and faster for our project to be designed. Here in below, there are some ideas about designing the feedback in our project:
    - Using only voltage comparator and compared with reference and drive the optocoupler
    - Using an analog circuit, in which we can use Operational Transconductance Amplifier to give the output of OTA to a power comparator then drive the optocoupler
    - Using a current comparator, voltage comparator and a circuit to compare and create power signal

After designing each part, we apply a remote transmission (Ethernet, or Radio, or GSM) which must be provided for sending data (operation and/or alarm).

1.16 Electrical characteristic

In this table, you can find the specifications of input and output characteristic of the project:

Table 3-1: Input and output electrical characteristics

Min Nominal Input Voltage	100 Vac	
Max Nominal Input Voltage	240	
Input Voltage	90-264 Vac	
Input Current	260 mA 560 mA	At 240V max load At 100V max load
Power Factor	0,95 0,99	At 240V max load At 100V max load
Output Current	0,35 A 0,7 A 1 A 1,5 A	Vedi impostazione dip Switch
Max Output Load Voltage	150 Vdc	
Min Output Load Voltage	100 Vdc	
Max Output Cable resistance	10 ohm	Con 1,5A la massima tensione di uscita ammissibile è 165V 150Vsul carico + 15V sui cavi
Ambient temperature MAX	50 °C	Massima temperatura ambiente operativa
Flash duration	100 ms 200 ms	Vedi impostazione dip Switch
Repetion rate	20 Flash/min 40 Flash/min 50 Flash/min 60 Flash/min	Vedi impostazione dip Switch

The output voltage until end of the project is not regulated by power supply, it depends on the load(number of LEDs at the output), since it is a constant current generator with different number of LEDs, output will be variable. Also, we have the possibility to put LEDs in series that has sum of Vf, so the total value will be in the range of (100÷160)Vdc .Output current can be adjustable from minimum 0.35A to 1.5A. Another point is that, the repetition could be slowly, for example 20 flash/min so we can calculate like below:

$$P_{max} \text{ during flash} = 160v*1.5A= 240watt$$

at maximum value:

$$P_{max} \text{ average} = 240watt\times0.2sec\times1Hz= 48watt$$

1.16.1 Standards

1. **IEC/EN 61347-1** –
   Lamp control gear - Part 1: General and safety requirements
2. **IEC/EN 61347-2-13** –
   Lamp control gear - Part 2-13: Particular requirements for d.c. or a.c. supplied electronic control gear for LED modules
3. **Cispr 15 / EN55015** –
   Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
4. **IEC/EN 61547**
   Equipment for general lighting purposes - EMC immunity requirements.
5. **IEC / EN 61000-3-2**
   Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)

1.17 Project block diagrams

Our whole project includes several parts which must be designed separately. Here is some part of designing:

1. EMC filter
2. Bridge rectifier
3. PFC Flyback
4. Microcontroller
5. Feedback circuit and optocoupler
6. Auxiliary Flyback
7. Boost converter
8. Buck control current output

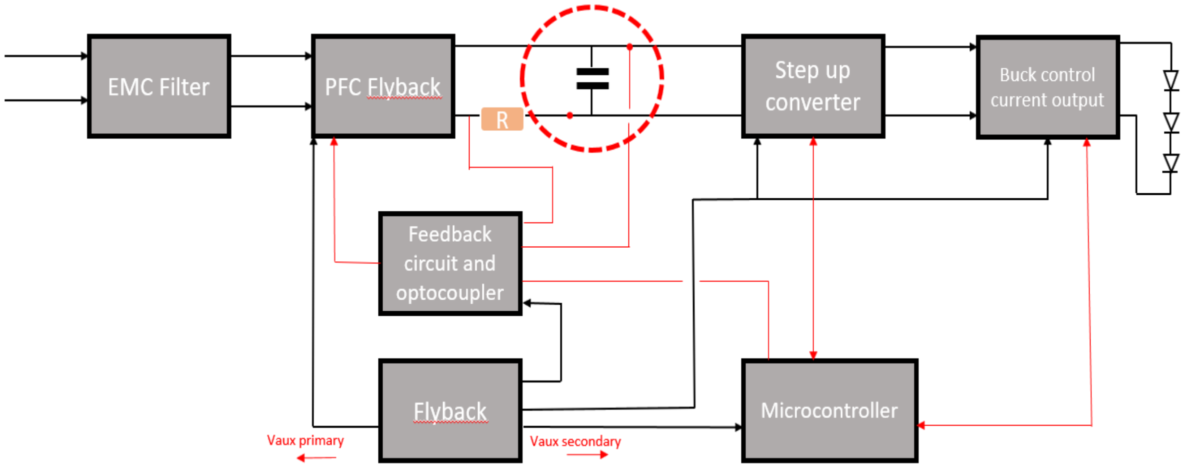


Figure 3-1: Connection of different parts of constant power supply

1.17.1 EMC Filter and bridge rectifier

An EMC filter is a filter that checks for electromagnetic compatibility. We get the emission and immunity standard for our project using this filter. Filters and chokes are used in EMC components to limit conducted electromagnetic interference to a degree defined in EMC plans, or to reduce it below the standards' limits. Figure down shows the design of EMC filter and bridge rectifier that made in Kicad for our project.

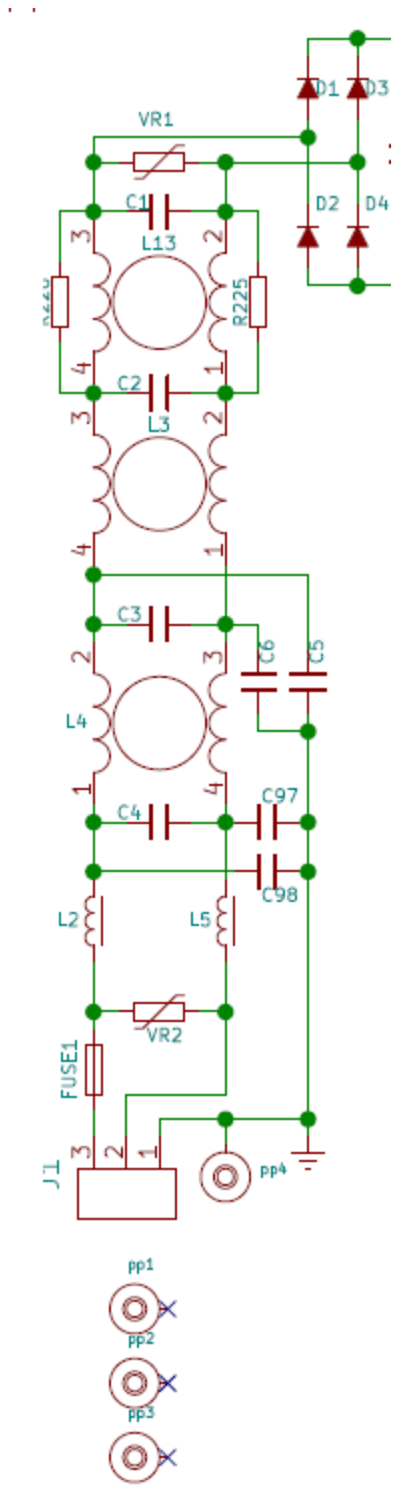


Figure 3-2: EMC and Bridge schematic

1.17.2 PFC fly back

Power factor correction fly back system is the core of the system which provide absorption by the mains, with high power factor and generate dc voltage isolated from the mains, for safety reason and safety standard. in this stage, we use an isolated transforming that made by galvanic insulation between the mains and capacitor (primary stage and secondary stage). In PFC Flyback power transfer is mainly magnetic field and there is no electrical connection between primary and secondary circuit. In figure below you can see the schematic of our PFC flyback designed in KICAD.

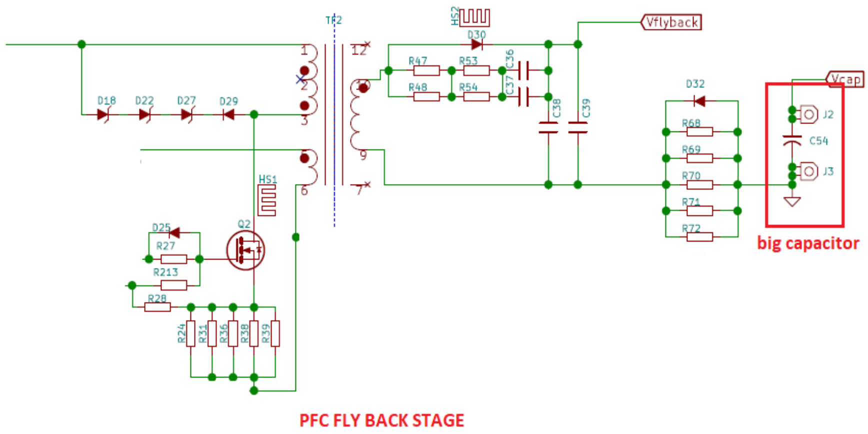


Figure 3-3:PFC Flyback converter schematic

1.17.3 Supercapacitor

In our block diagram there is a big typical capacitor to accumulate the energy, but this capacitor has no characterization for charge and discharge, on the other hand, we cannot use supercapacitor, since super capacitor has very low maximum voltage (around 2.8v) and also it is difficult to put in series.

In this project, we found a capacitor with a thermocouple inside, the benefit of this kind of capacitor is that during the test we can measure the temperature and it has high voltage. In figure 3-1 you can see the placement of this capacitor between two stages of PFC flyback and step up converter.

1.17.4 Step up converter (Boost converter)

Step up converter (boost) transforms the voltage from capacitor which is around (20V÷90V) to DC voltage around 210V.

1.17.5 Auxiliary power supply

It is necessary to realize a buck stage to generate 12V and 5V (or 3.3V) to supply the microcontroller and feedback circuit in secondary side of PFC flyback.

1.17.6 Buck control current output

Since our circuit designed to have constant current at the output for LED, we use bulk control current output for driving LEDs. so, we can generate 1.5A maximum depends on demand, at the output.

1.17.7 Feedback circuit and optocoupler

In the feedback, it needs to check current, voltage and signal with their reference and gives signal at the output of comparator and make the optocoupler activate. In the part of feedback principal circuit, we will read more about working function of them.

1.17.8 Microcontroller

For sending all these signals for all different parts we need to manage them by a powerful microcontroller cortex M0.

1.17.9 Feedback circuit principle

Feedback reads parameter at the output of the comparators and drive optocoupler which is connect between feedback part of circuit and PFC flyback part, to manage constant voltage and/or constant current or power as you can see in the figure 4-4. The capacitor will accumulate energy during output off time and supply the output during on time to obtain average constant power from the input. So, it is necessary that, the feedback circuit manage also constant power. Here is the characteristic plot for Vout -Iout in figure below:

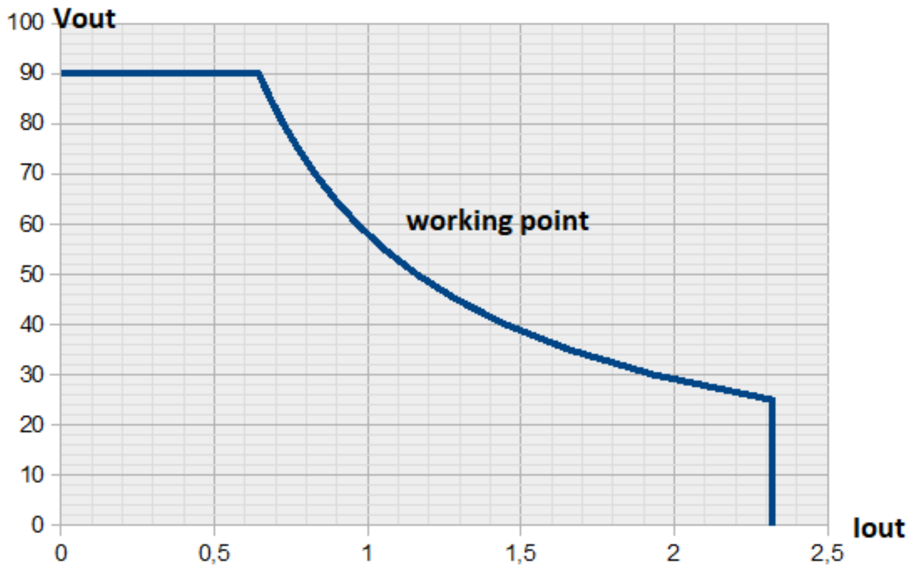


Figure 3-4: Vout-Iout characteristic

The explanation of working principle is that, capacitor will be continuously charged and discharged and the maximum power that we can obtain, is the parabola curve in figure 6 that is called working point.

Output current is the current in the capacitor that goes to output.so, if we have constant power (V×I=constant), the current in the capacitor depends on its voltage. Managing of the feedback is that, when we have flashing the capacitor must be discharge and when we have no flash, the capacitor must be charge. By calculation the energy in the capacitor, we can design suitable capacitor for our project as you can see in the table 3. We have chosen the capacitor that has maximum and minimum voltage of 90v and 25v respectively. We choose this voltage value for some reasons:

- Keep the capacitor voltage below 120 Vdc to consider SELV (safety extra low voltage) circuit for safety aspect.
- The electrolyte capacitors have voltage of 63v÷100v or 160 Vdc.
- The maximum voltage of 90 Vdc is for having safety margin towards the maximum capacitor voltage.
- The minimum voltage of 25v is to avoid exceeding the current

Table 3-2: Capacitance calculation

1	**Calcoli delle energie e potenze in gioco in Atx constant power**							
2	**Grandezza**				**Valore**	**U.M.**		Note:
3	Corrente impulso	Flash current	I_{LEDs}		1.5	A		Green cells: put here data
4	Tensione LED	LEDs voltage	VLEDs		160	V		Yellow Cells: automatic calculation
5	Potenza ist impulso	Flash power	P_{IMP}		240	W		
6	Durata impulso	Flash duration	T_{IMP}		0.2	sec		
7	Freq ripetizione imp.	Flash repetition freq	Freq.		60	Flash/min		
8	Freq ripetizione imp.	Flash repetition freq	Freq.		1	Hz		
9								
10	Energia impulso	Flash energy	E_{IMP}	$I_{LEDs} \times V_{LEDs}$	48	J		
11	Potenza media	Average power	P_{AVG}	$E_{IMP} \times Freq$	48	W		
12	Potenza ausiliaria di funzionamento	Auxiliary and controll circuit power	P_{aux}		5	W		
13	rendimento stadio out	output stage efficiency	n_{OUT}		0.9	%		
14								
15	Potenza che deve essere fornita dallo stadio di ingresso.	input power (power that come from the mains)	P_{STImin}	$(P_{AVG} + P_{aux})/n_{OUT}$	58.9	W		
16								
17	Dimensionamento stadio di ingresso	estimated input power stage	P_{STI}		60	W		
18								
19	Potenza che deve essere fornita dal condensatore	power that the capacitor supply to the output stage	P_{COND}	$P_{COND}=(P_{flash}-P_{STI})$/output stage efficiency	200	W		
20	Energia che deve essere fornita dal condensatore	energy that must be supplied by the capacitor at every flash			40	J		
21	Tensione nominale del condensatore	Nominal voltage of capacitor			100	V		
22	Tensione max applicata	maximum voltage on point 2 of the graph			85	V		
23	Tensione minima di funzionamento	voltage on point 1			30	V		
24	Capacità minima necessaria	minimum capacitance necessary			12.65E-3	F		
25	Capacità del condensatore a finevita con minima tolleranza	Reduction of the capacitance due to the tollerance and end of life of the capacitor			60	%		
26	Capacità minima del condensatore	minimum nominal value of the capacitor			21.08E-3	F		

As you see in the table above, minimum nominal value of the capacitor is 21mF, so we choose the capacitor with 22000uF with 100v (Epcos).

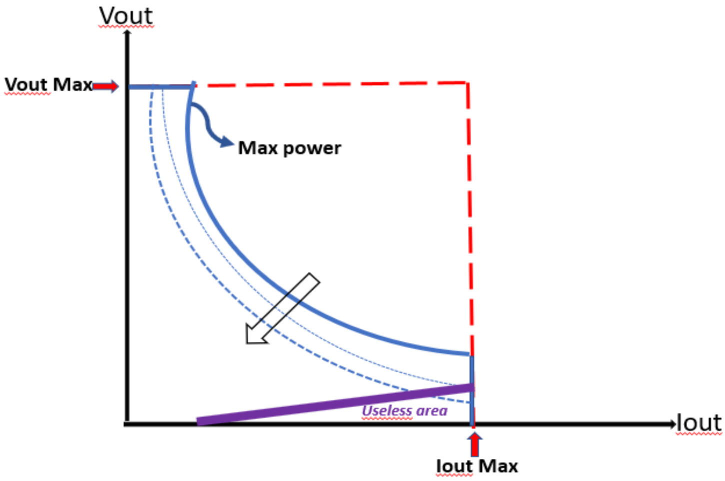


Figure 3-5: Vout-Iout characteristic and useless area

As you can see in figure above, for managing the circuit for not going in the useless area, we use a microcontroller to manage the feedback circuit and all signals related to feedback signals.

4. Designing of Constant power supply

1.18 PFC Flyback

For designing PFC fly back, first we consider L6562AT.

1.18.1 Transition-mode PFC controller (L6562AT)

PFC flyback characteristic calculation For PFC Flybac, we chose L6562AT. The current mode PFC controller integrated system is an IC intended to control PFC preregular by using the Transition Mode technique which is suitable for our project. But, Since We could not put the dead time in the calculation because we can't measure it very precisely, so in our calculation we put correction factor that we can change it whenever we want until we obtain same power around peak.

In table below, you can find some necessary values of our design.

Table 4-1: PFC flyback characteristic calculation

Item	Value	Symbol	Rating
Correction factor	0.056	corr	-
frequency	70.33	f	kHz
Voltage on capacitor	30	V_{cap}	V
Input power	60	P_{in}	W
Turn ratio	3	N	-

After calculation we see a variety of frequency range and since this L6562AT is working on different range (there is too large slope working frequency), on the other hand the filtering of this frequency range is difficult and we will have switching frequency loss, so we decided to change the IC to find better condition. The new IC that we choose, is very similar to L6562AT, the name of new IC is called HVLED001B.

1.18.2 High power factor flyback controller with constant voltage primary-sensing and ultra-low standby consumption HVLED001B

HVLED001B works in the same way, that L6562AT works, the difference is minimum frequency, as soon as frequency will increase, the IC will remain at low frequency (in high frequency it will artificially stop to reduce the frequency).in our calculation to obtain this minimum frequency, we need to find a very low value inductance.so, we have to find the new value for primary and secondary inductance in designing of PFC fly back, in a condition that we decided to have min frequency(more or less 40kHz), so for this condition we select the minimum value for the input voltage and also voltage on the big capacitor.

Here in the table below we have the results for correct value of the inductance for PFC flyback in our project.

Table 4-2: Inductance parameter of pfcflyback

Item	Value	Symbol	Rating
Peak current primary	6	I_{P_pk}	A
airgap	2	Air_{gap}	mm
Magnetic flux density	0.1967	B	T
inductance	450	L	uH

In our calculation we did not consider dead time on Ton and Toff , instead we put Correction factor in the calculation. To obtain constant voltage for PFC flyback optocoupler, normally it is not necessary to have feedback circuit but since we are working in constant power, we need feedback regulation. This integrated circuit has a disadvantage. At the start up, when we switch on the system, we have a big capacitor on the output of PFC flyback which is completely discharged so with this type of circuit, it acts like a short circuit. So, in this situation the circuit is not able anymore to start again because when it begins to start, it will see all the time a short circuit path and integrated circuit will be off while sees this short circuit.

As a solution for this kind of disadvantage we have designed two possibilities:

1. We can put a relay like figure below, so in this solution the circuit charges the capacitor slowly. Principle of working is that, in figure 4-1 when the MOSFET is on, PFC Flyback will see the resistor (R1) instead of short circuit to ground, so MOSFET will give a little current to charge the capacitor slowly, then when the capacitor will reach to enough value, relay will be closed in parallel to the resistor (R2) to short circuit the (R1). as the capacitor reaches to 30V, the relay will energize and will close, so it overdrives the R2.

   (we did not use this solution in our schematic)

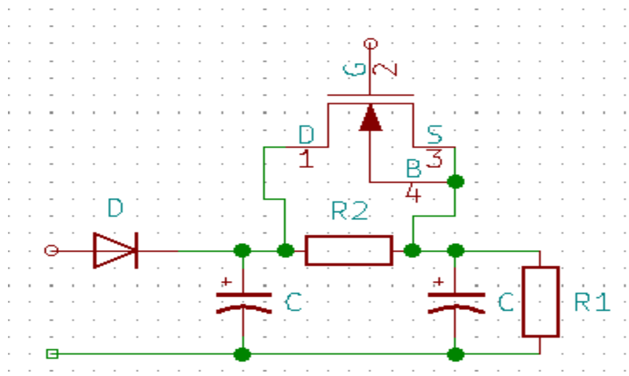


Figure 4-1: Relay schematic

2. Another solution is that we can use auxiliary circuit that we designed by an IC, called VIPER22 ST microcontroller. We design this auxiliary supply with small flyback (it normally takes 4÷5 watt). We know auxiliary circuit produces different voltage, so we can use these voltages and feed the other parts of circuit by its secondary side voltage. with this solution, while the short circuit happens at the output of PFC flyback, it can supply with constant current and never seen short circuit so we can obtain the typical output characteristic of PFC or PFC flyback like in the figure below.

   On the other hand, this solution has a disadvantage, the IC that we use as flyback, is a standard flyback not a PFC flyback so during running function, it will create a little bit distortion on input current peak that can be solved by adding a filter at the input.

   Figure below shoes the block diagram of the connection between PFC flyback signal and auxiliary power supply signal.

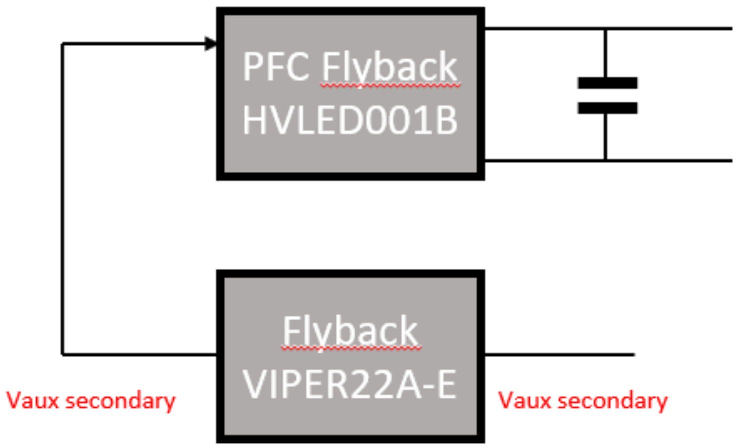


Figure 4-2: Connection of auxiliary and flyback

1.18.3 Designing of PFC Flyback with HVLED001B in Kicad

Here is the full schematic of our designing of a PFC flyback converter. As you can see in the figure below, on the right side of schematic, the secondary side of PFC Flyback consists current sense and a capacitor to give DC voltage to the supercapacitor:

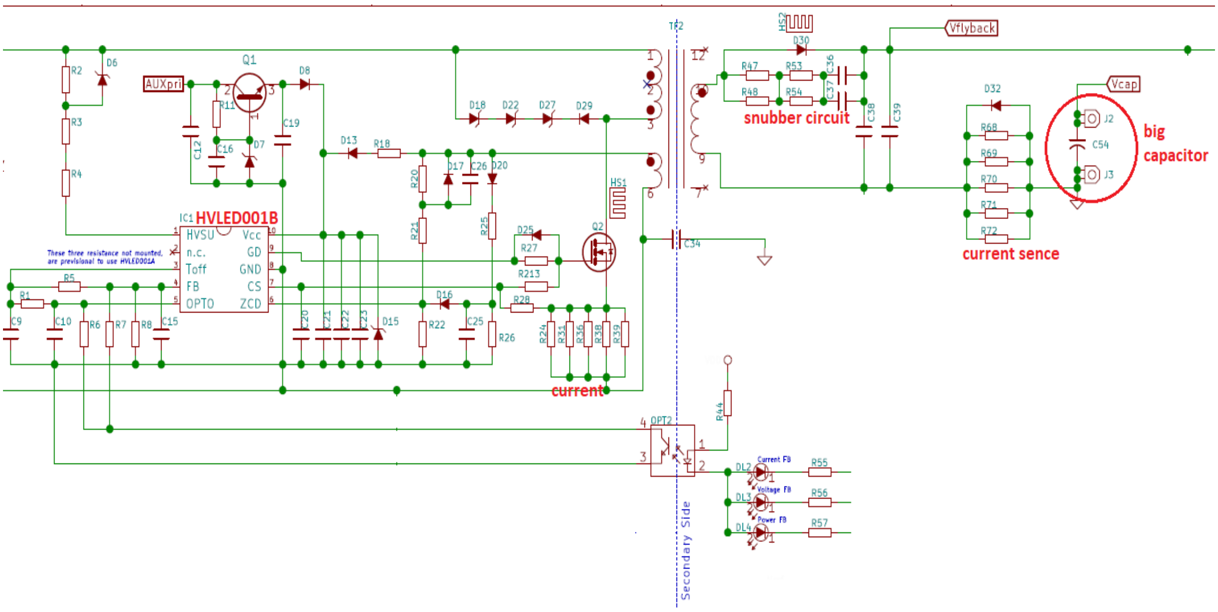


Figure 4-3: PFC flyback schematic

1.19 Feedback circuit and optocoupler

Since at the secondary side of PFC Flyback there is negative current, so we decide to use an operational amplifier to read the negative current and then we have three comparators for reading current, voltage and power.

1.19.1 Designing of feedback circuit and optocoupler

For the designing of the feedback circuit, we use also provisional circuit to have maximum current on diodes (DL2, DL3 and DL4) so the circuit can work perfectly (inhibit PFC signal read by microcontroller).

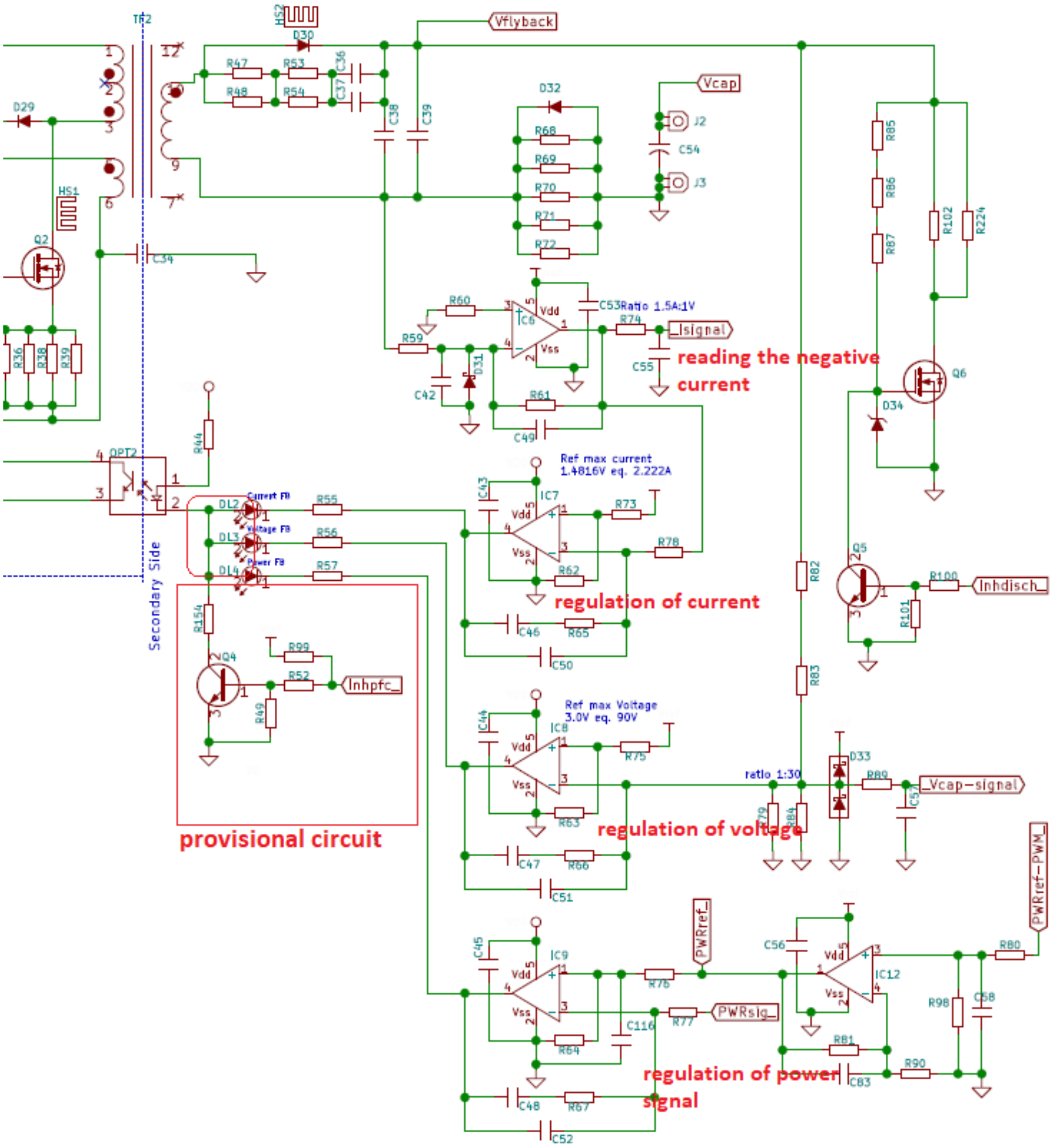


Figure 4-4: Feedback circuit schematic

In figure above, the three amplifiers work in different ways and they are the core of feedback network. they work in parallel by the diodes (DL2, DL3 and DL4). If one of the outputs of these opamps is lower than its reference value, that opamp will generate feedback signal to drive optocoupler which is connected to PFC flyback. For such feedback we need two DACs of microcontroller (digital to analog converter) to create power signal and power reference on the feedback.

1.20 Auxiliary Flyback

For the auxiliary flyback we decide to use for our project VIPer22A-E which has power mosfet inside. by help of the second side of the auxiliary circuit we can also supply other parts of project, for example external devices and to not have short circuit on PFC flyback that we already discuss (as solution, to avoid HVLED001B sees any short circuit).

1.20.1 Designing of Auxiliary Flyback by VIPer22A-E

As it shown in the figure below, we used an optocoupler to use our secondary side to feed by power to the other parts of circuit.

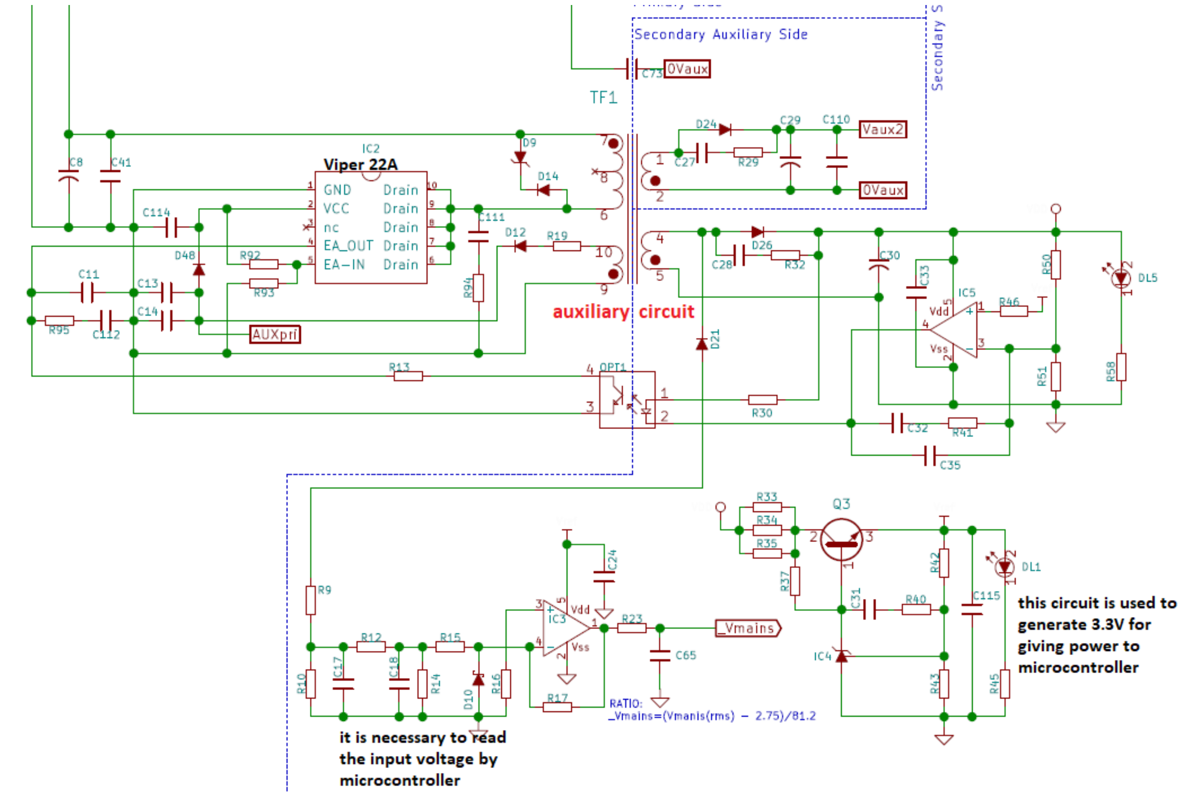


Figure 4-5: VIPer 22a design schematic in Kicad

1.21 Step up converter (Boost)

This converter converts the voltage of big capacitor to higher voltage to supply the last stage of the circuit that is Buck current generator. As we know, we have the minimum and maximum capacitor voltage in the range of 25V÷95V (charging and discharging) at the input of boost converter as an input voltage for this stage. at the output of boost the voltage is, more or less 210Vdc (high voltage). for this stage we used L4984D CCM PFC controller.

1.21.1 Designing of the Step up (Boost) converter by L4984D

You can find the schematic and designing of all pins of L4984D for boost in figure below.

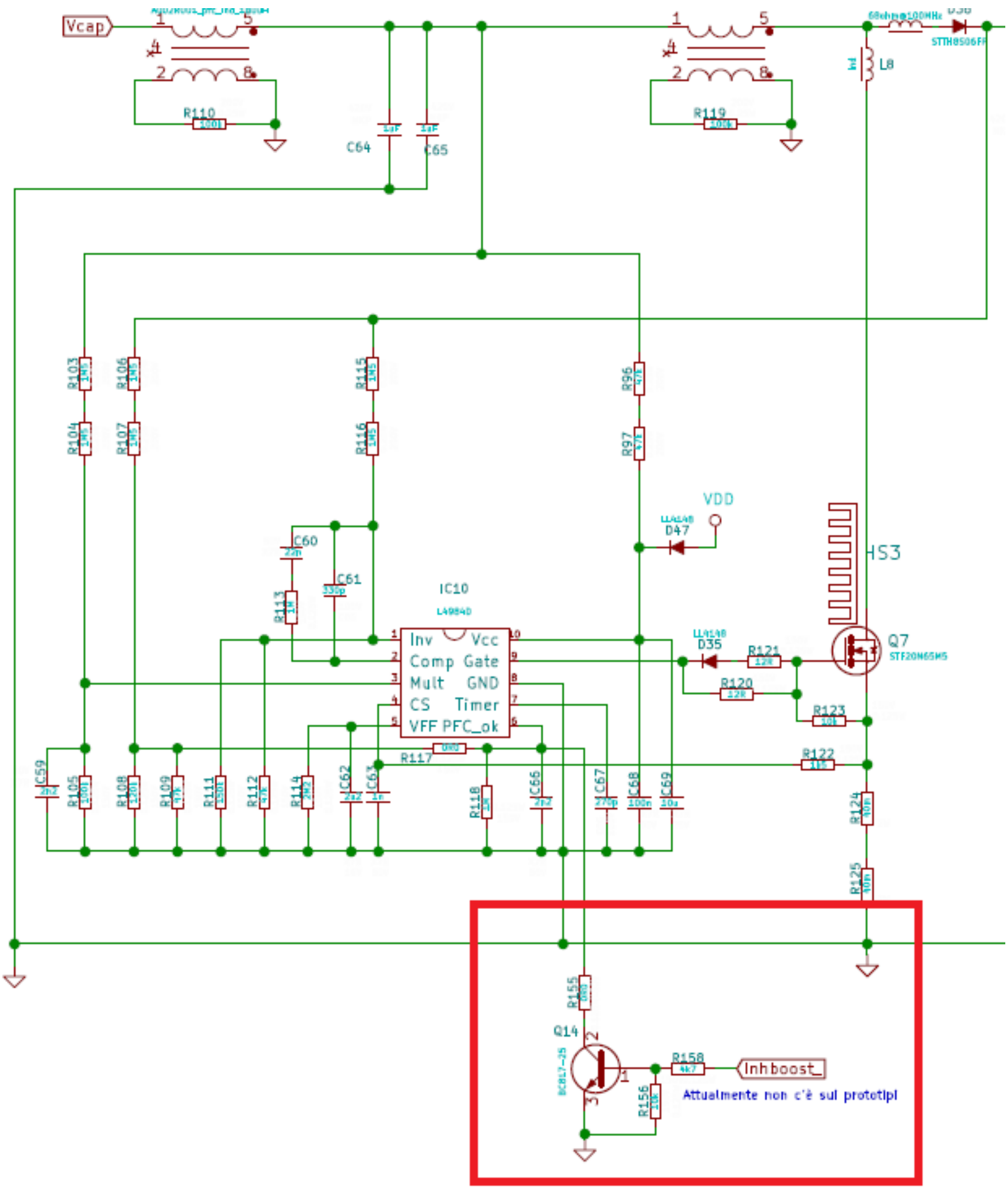


Figure 4-6: Step up (Boost) converter schematic

1.22 Buck control current output converter

For generating the current needed for LEDs at the output, we will use L6395D high voltage high and low-side driver from STmicroelectronics.

1.22.1 Designing of Buck control current output by L6395D ST

Here you can see the all the connections of the pins of L6395D IC in figure below. for our buck we use the high side voltage mode. So, with 210Vdc which comes from boost stage, for our power MOSFET to carry this high voltage, we choose STD16N60M2 600V for commercial reason and since the voltage is around 210Vdc.

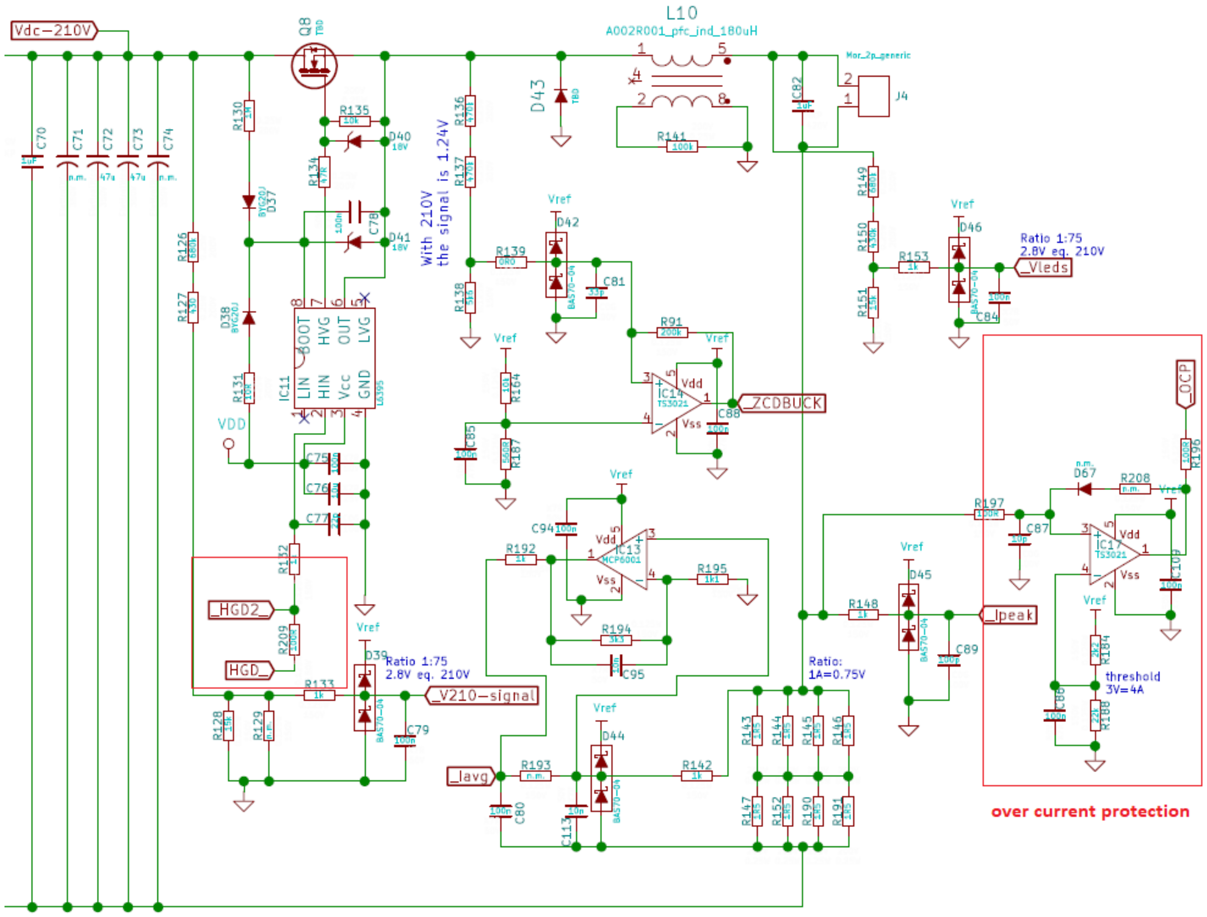


Figure 4-7: Buck current control

1.23 Microcontroller

In our project we use microcontroller STM32G081RBT6 with 64 pins to able to have 128k flash.

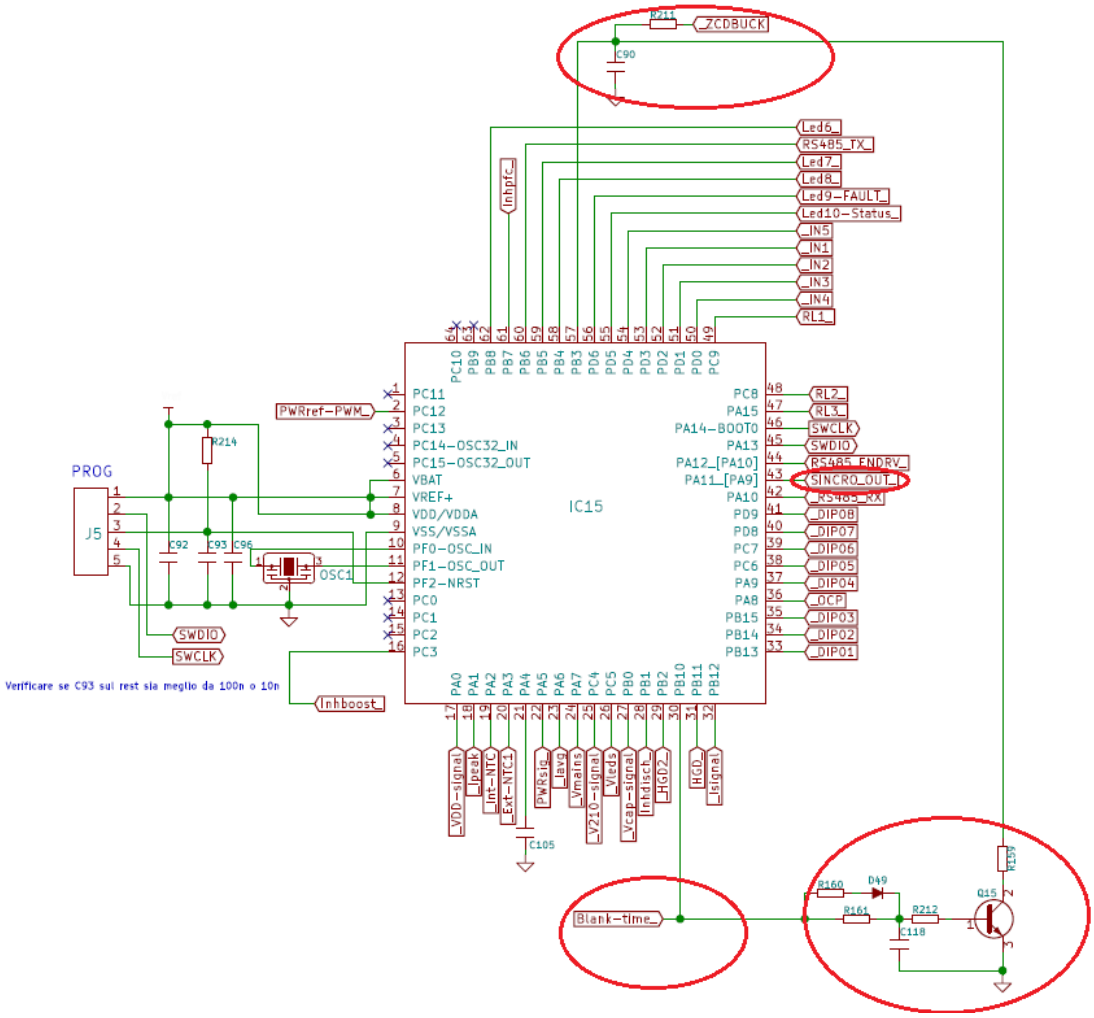


Figure 4-8:: microcontroller pin schematic connection

1.23.1 Clock

We have three types of clock that we can choose for microcontroller:

1. Internal clock which is cheaper since it is exist in the microcontroller and it is not precise so we will not use this for the clock of our microcontroller.
2. External ceramic resonator which is precise and cheap, and we use this for our application.
3. External quartz resonator which is precise but more expensive and we did not use in our project.

1.24 Choosing input and output function for constant power supply

In the figure 4-9, you can find the connections for giving functions as input or output for the project that this functionality choose by VDGLAB.

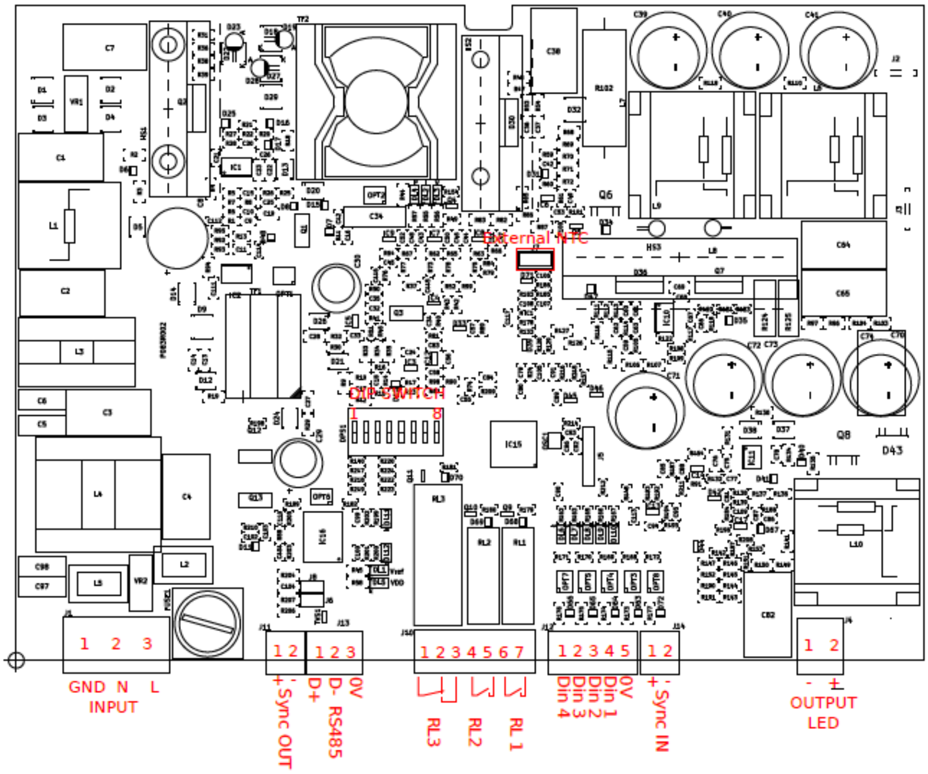


Figure 4-9: Constant power supply board schematic

1.24.1 18 dipswitches (DPS1):

As shown in table 5-1, we can set our output current to four different values for the LEDs, the duration of the Ton, and the number of flashes per minute, among other things.

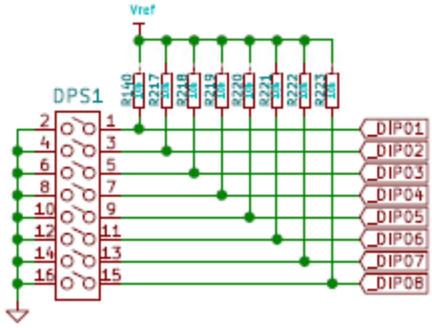


Figure 4-10: 18 dipswitches (DPS1):

1.24.2 Sincro_Out:

Connector J11, act as a master in which you can have communication with other board as slave and start to flash on and off time at a same time (time synchronization), so we can connect different modules of LEDs as a array and manage them at the same time.

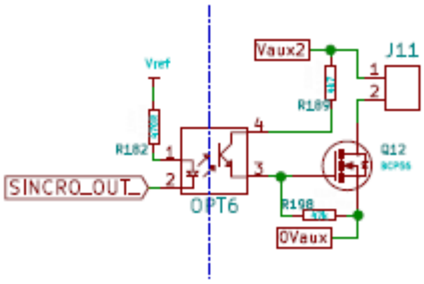


Figure 4-11: Sincro_Out

1.24.3 Five opt insolated input:

One of this opt insolated is for Syncro_In connected to J14 and the other four which is connected to J12 for digital insolated input (4 digital input). As shown the schematic in the figure 4-12.

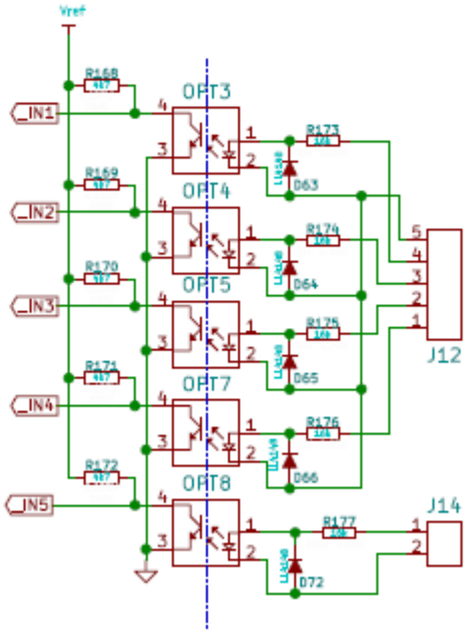


Figure 4-12: 5 opt insolated input

1.24.4 Three Relays:

double insulation to digital input by the board but not isolated from each other, connected to J10.

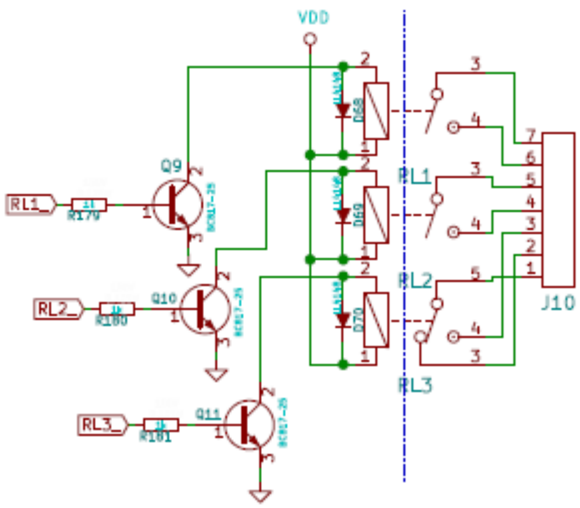


Figure 4-13: Three relays

1.24.5 External negative temperature coefficient:

We can choose the temperature of where we want to measure by connecting this sensor which placed on J7.

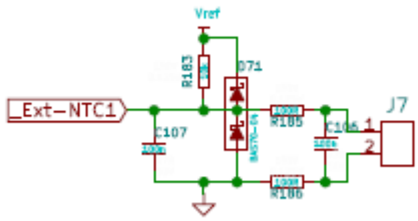


Figure 4-14: External NTC

1.24.6 RS485 serial communication:

We can communicate through the RS485 with other devices through J13.

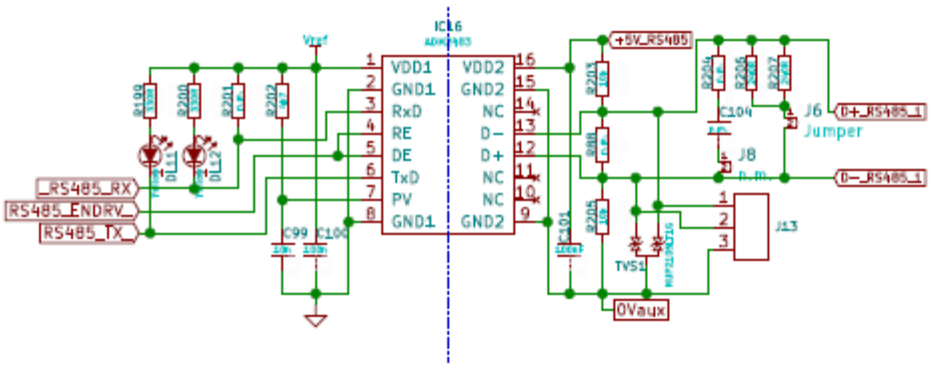


Figure 4-15: RS485 serial communication

1.25 3D CAD model of the PCB board

Once we finish the design of the schematic, we move towards the PCB layout design of our project. After a careful routing process, we come to the final look of constant power supply.

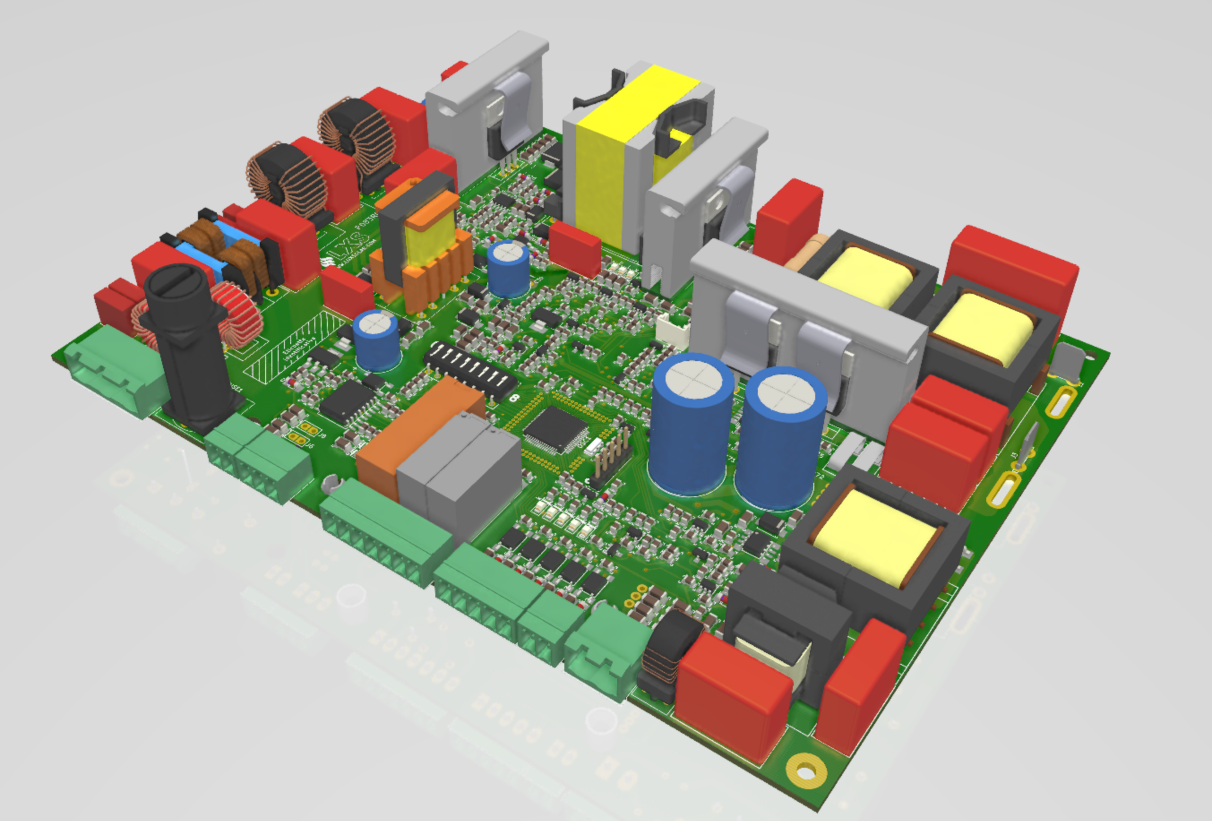


Figure 4-16: 1.13d CAD Model of the PCB board

5. Results and Discussion

Analytical derivation of a constant power supply behavior based on the parameter set at the output such as current at the output set by dipswitches to have 350mA, 700mA, 1000mA, and 1500mA during flashing time and variable flashing time with the duration equal to 100ms and 200ms, taking into account operating temperature and capacitor age. Although we can set the flash per minute at the output by dipswitches to 20, 40, 50, and 60 flashes per minute.

1.26 Principle of operation

When constant power supply starts working, the microcontroller reads the setting of the dip switches and prepares for operation. It forces a limitation of the power of the PFC-Flyback circuit according to the expected power. With this setting, it charges the capacitor in two phases.

A first phase with a fixed power limitation and the second part with limitation depending on the configuration, subsequently it generates the current pulses at the output. At each pulse it reads the capacitor charge voltage immediately before the pulse comes and modulates the power limitation to always have a capacitor voltage, before the pulse, between 85 and 90V.

The correction of the power limitation is not continuous but is corrected and / or updated at each pulse. Depending on the load and the tolerances of the various parameters it is possible that the regulation is not fast enough to guarantee the charging of the capacitor and in the first few minutes some pulses may be omitted.

The purpose of constant power supply is:

- Cable sizing reduction and length switch protection
- Flashing for drying special parts of x-y axis of labels (not continuously)
- Remote control of each module of UV LED
- Fast switching

For the verification of the constant power supply design various test were performed by setting dipswitches. The following table shows possible setting of the dipswitches and their relative purpose.

Table 5-1: DIP switches setting.

DIP 1	DIP2	Settaggio corrente		
0	0	350 mA		
1	0	700 mA		
0	1	1000 mA		
1	1	1500 mA		
DIP 3		**Sincro**		
0		interno		
1		esterno	NON ANCORA IMPLEMENTATO	
DIP 4		**TBD**		
0		… …		
1		… …		
DIP 5		**Lamp duration setting**		
0		100 ms		
1		200 ms		
DIP 6		**TBD**		
1		… …		
2		… …		
DIP 7	**DIP 8**	**Lamp frequency setting**		
0	0	20 Flash/min	0,33333 Hz	3 s
1	0	40 Flash/min	0,66667 Hz	1,5 s
0	1	50 Flash/min	0,83333 Hz	1,2 s
1	1	60 Flash/min	1 Hz	1 s

The two figures below show the operation with maximum load and maximum resistance of the connection cables. When the constant power supply turned on and after 10 minutes of operation it gets stable.

Figure 5-1: Operation with maximum load and maximum resistance of the connection cables

1.27 Fault status

The board goes into a Fault condition in cases of where there is no load or short circuit at the out put.

1.28 Available resources to implement

1.28.1 NTC INTERNAL

Electronic board temperature reading by NTC mounted on board. This values reads by microcontroller. The placement of the NTC shown in the figure 5-2.

1.28.2 NTC EXTERNAL

We have another temperature reading via external NTC on the board that The type and the response curve must be defined.

As you can see in the figure below the place of both NTCs.

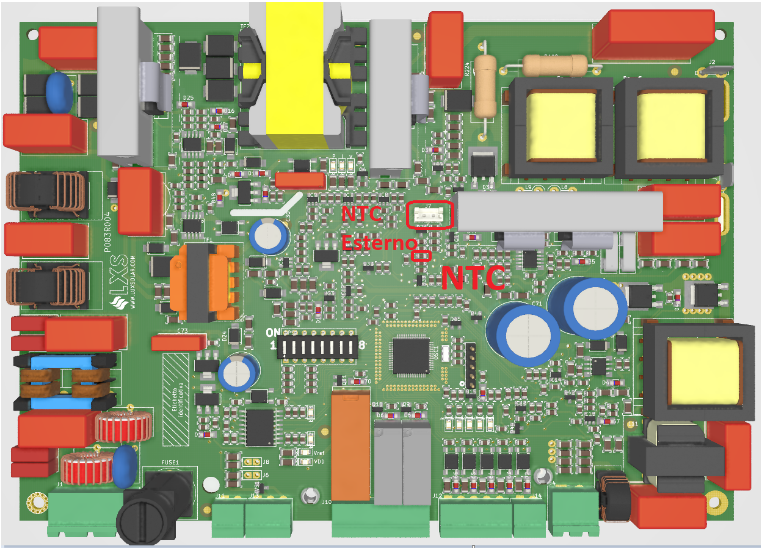


Figure 5-2: NTC Internal and External

1.29 Bench measurements

Dipswitch 1 and 2 represent the current set at the output. And dipswitch 5 shows the duration of Ton. The more current is set, the more power is provided to the LEDs.

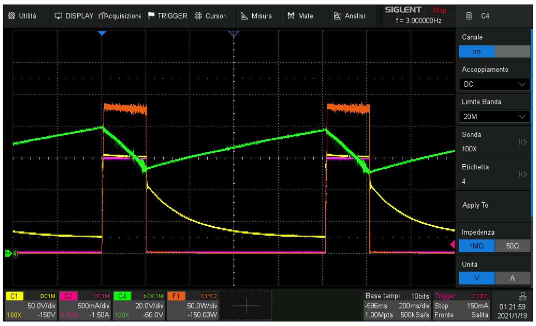
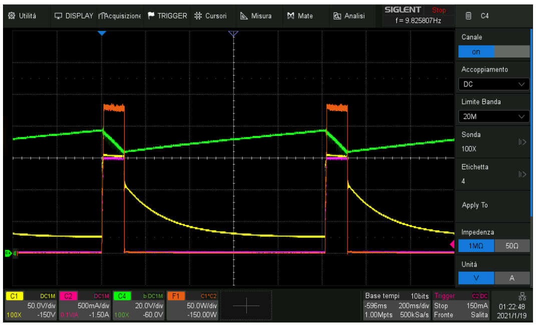
We can verify different settings of dipswitches one by one by the help of oscilloscope as all the conditions tested and the results shown in below which is related to each flash per minutes.

In the plots below:

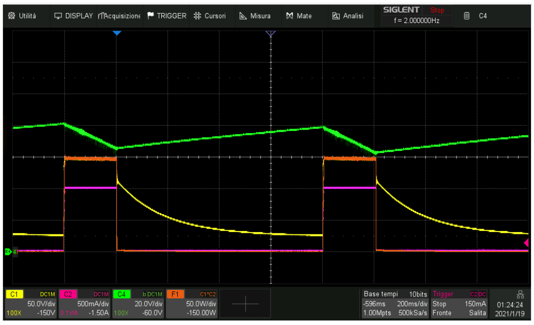
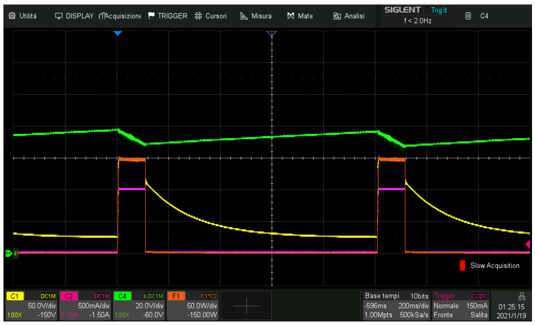
- *CH1 represents output voltage*
- *CH2 represents output current*
- *CH4 represents the voltage on the capacitor(charge and discharge)*
- *Math1 shows output power during flashing.*

1.29.1 60Flash/min

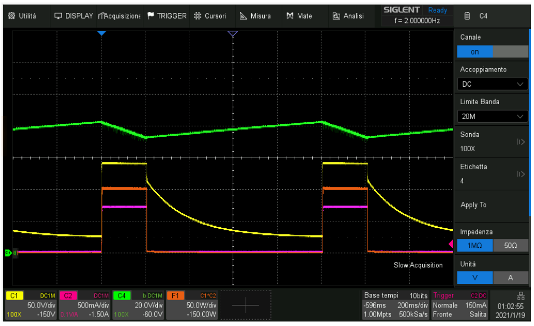
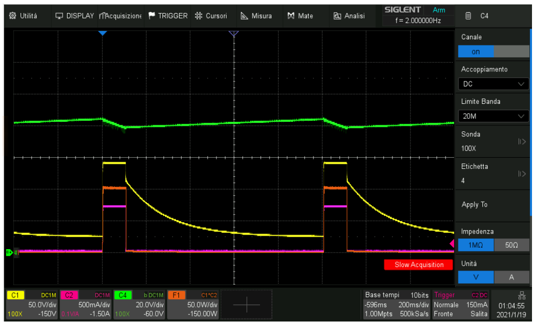
Iout set to 1,5A; Ton on the left is 0,2s and on the right is 0,1s; 60Flash/min

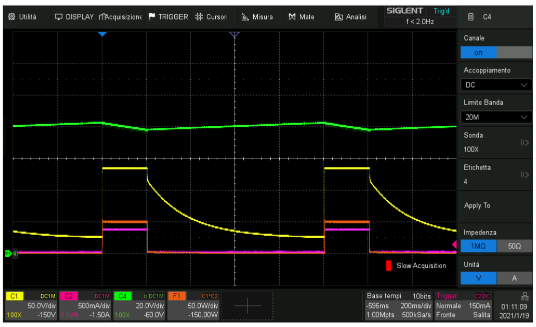
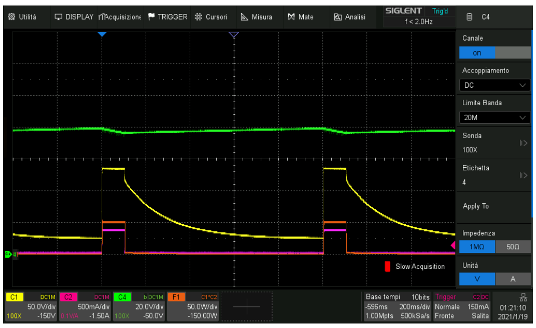
Iout set to 1,0A; Ton on the left is 0,2s and on the right is 0,1s; 60Flash/min

Iout set to 0,7A; Ton on the left is 0,2s and on the right is 0,1s; 60Flash/min

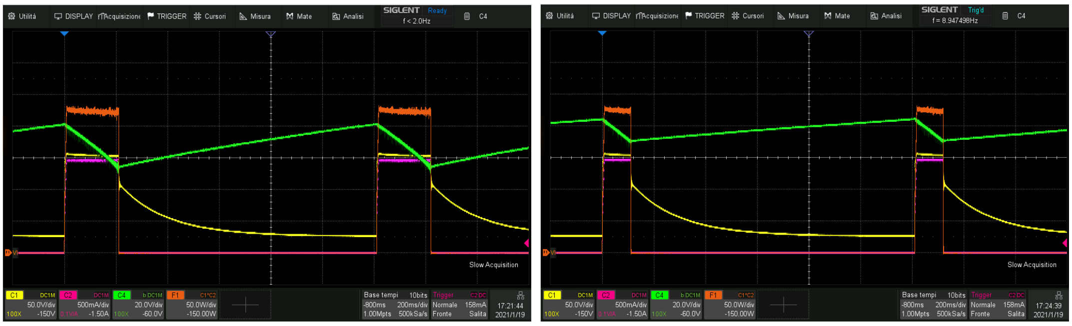



Iout set to 0,35A; Ton on the left is 0,2s and on the right is 0,1s; 60Flash/min

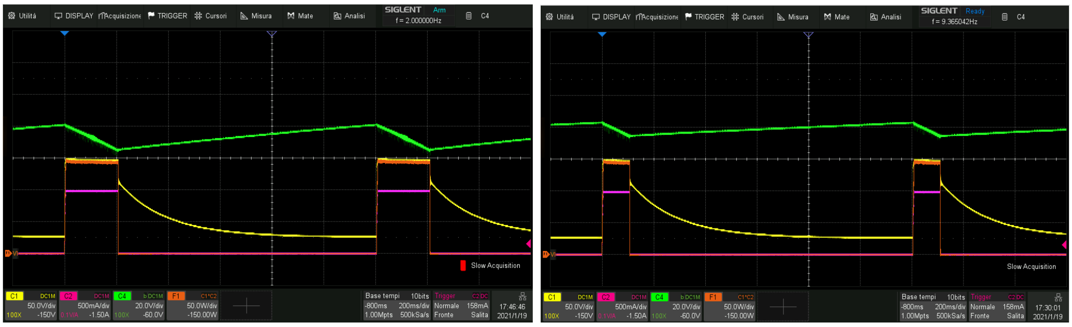



1.29.2 50Flash/min

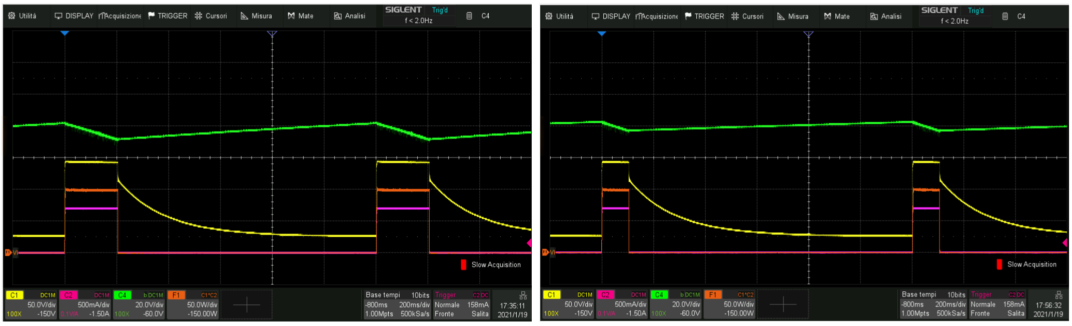
Iout set to 1,5A; Ton on the left is 0,2s and on the right is 0,1s; 50Flash/min



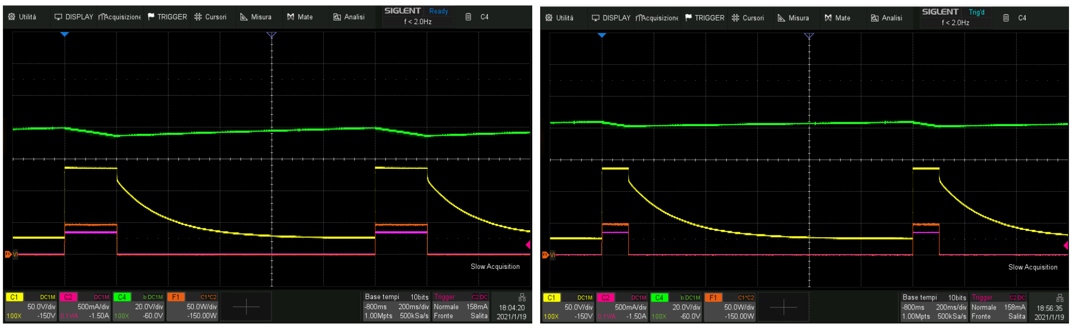
Iout set to 1,0A; Ton on the left is 0,2s and on the right is 0,1s; 50Flash/min



Iout set to 0,7A; Ton on the left is 0,2s and on the right is 0,1s; 50Flash/min

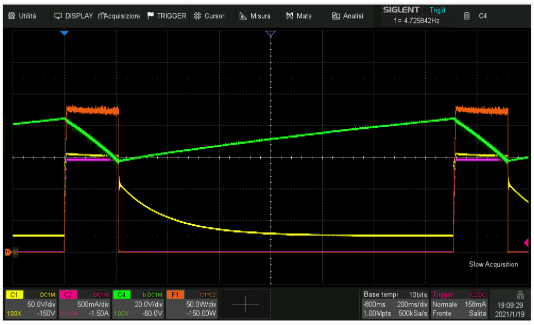
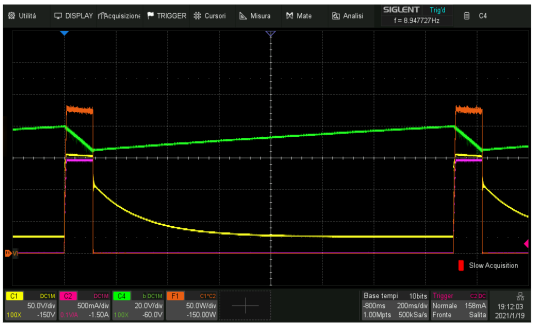


Iout set to 0,35A; Ton on the left is 0,2s and on the right is 0,1s; 50Flash/min

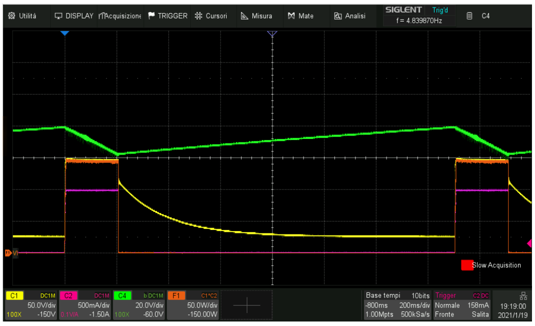
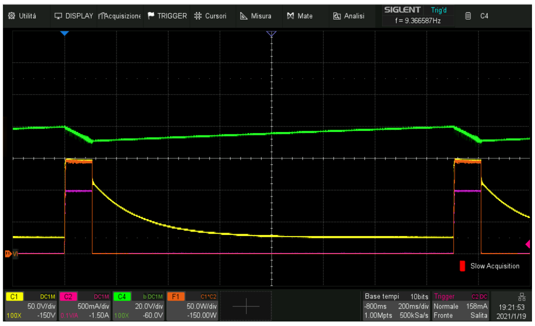


1.29.3 40Flash/min

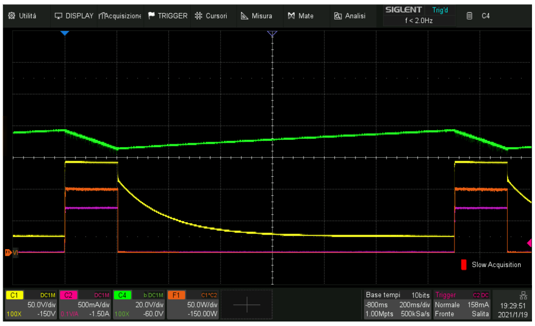
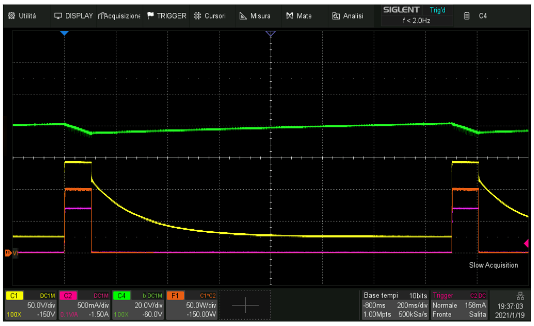
Iout set to 1,5A; Ton on the left is 0,2s and on the right is 0,1s; 40Flash/min

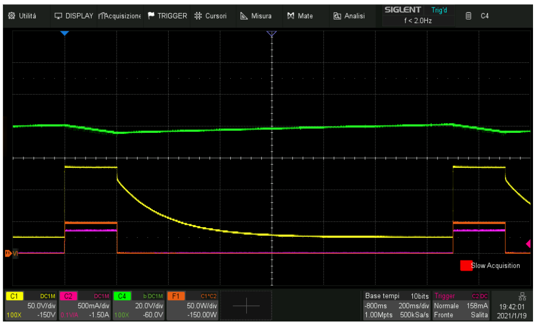
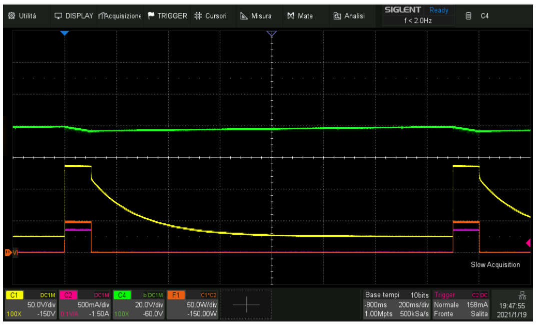
Iout set to 1,0A; Ton on the left is 0,2s and on the right is 0,1s; 40Flash/min

Iout set to 0,7A; Ton on the left is 0,2s and on the right is 0,1s; 40Flash/min

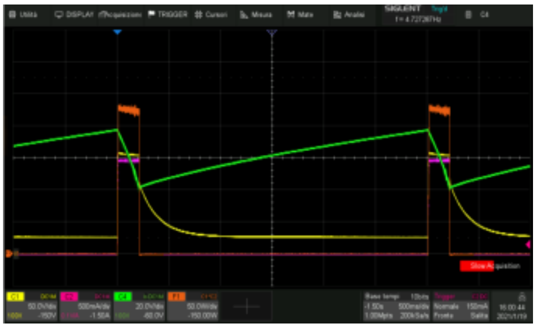
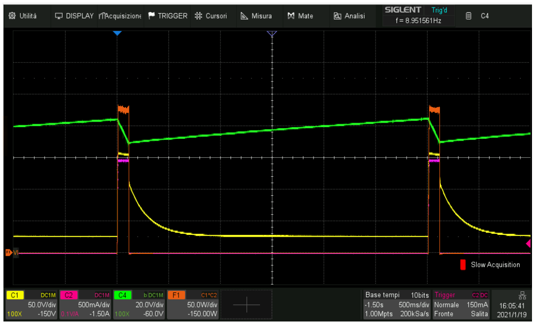



Iout set to 0,35A; Ton on the left is 0,2s and on the right is 0,1s; 40Flash/min

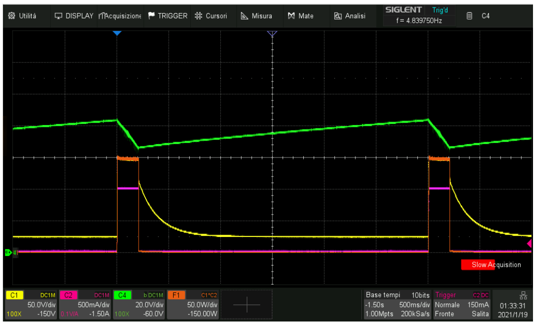
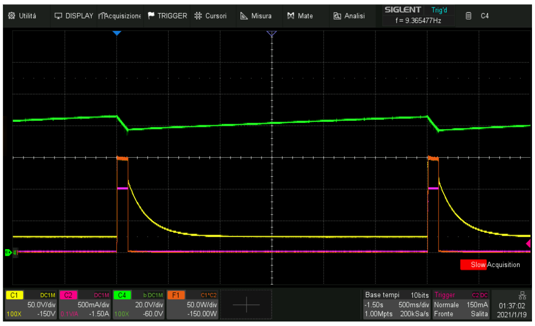



1.29.4 20Flash/min

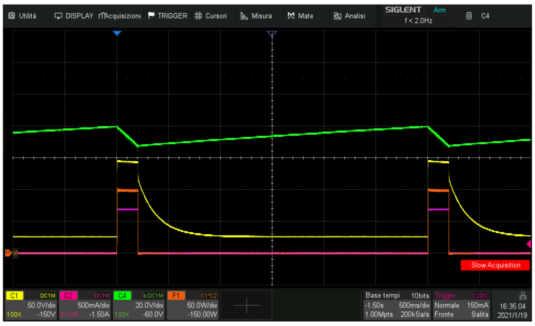
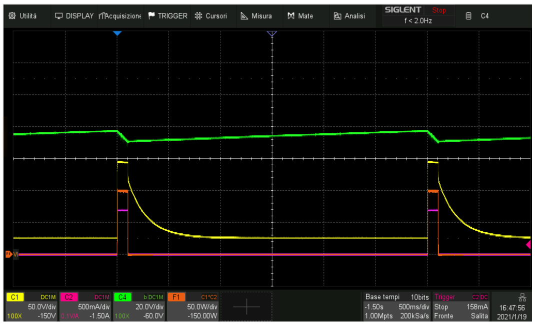
Iout set to 1,5A; Ton on the left is 0,2s and on the right is 0,1s; 20Flash/min

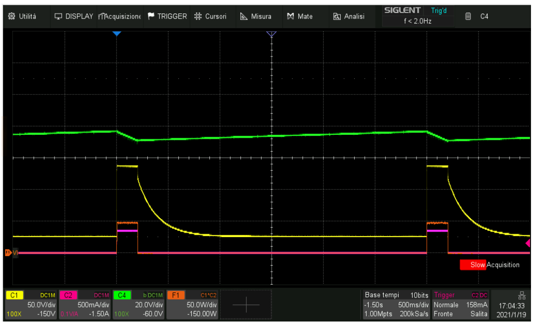
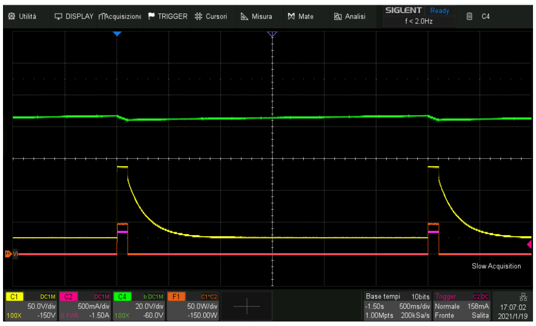
Iout set to 1,0A; Ton on the left is 0,2s and on the right is 0,1s; 20Flash/min

Iout set to 0,7A; Ton on the left is 0,2s and on the right is 0,1s; 20Flash/min

Iout set to 0,35A; Ton on the left is 0,2s and on the right is 0,1s; 20Flash/min

1.30 Electromagnetic compatibility (EMC)

As we mentioned the standards, Partial pre-compliance measures according to EN55015. As you can see in the figure 5-3 electromagnetic compatibility test for our project.

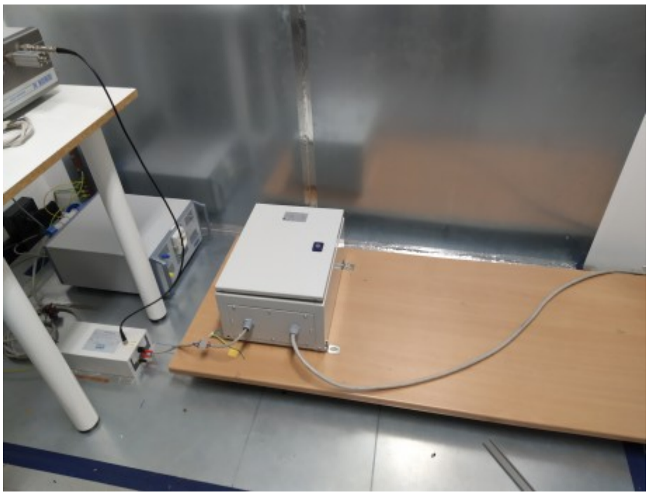


Figure 5-3: Electromagnetic compatibility

1.30.1 Measurement setup and notes

To obtain compliance with the limits, two ferrite filters were introduced on the connection cables.

Ferrite Fair-Rite cod. 0461167281 on both connection cables to the storage capacitor.

Ferrite Fair-Rite cod. 2631665702 with 2 turns (i.e. two passages and the hole) for both cables of the OUT connection. Furthermore, the position of the internal components has been redesigned to remote the thermal breaker and in general the input connections from the capacitor.

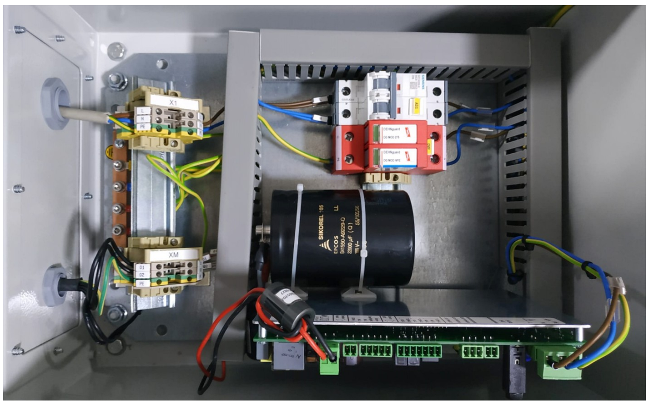


Figure 5-4: Ferrite filters on the connection cables

1.31 Conduct

1.31.1 9kHz-30MHz Line (test n 085)

The measurement is performed only as a Peak for the variation of the limits between 9kHz and 150kHz. For the second frequency range with Quasi Peak and Average measurement, see the following measurements. As it shown all the waveforms are under the mask and safety margin.

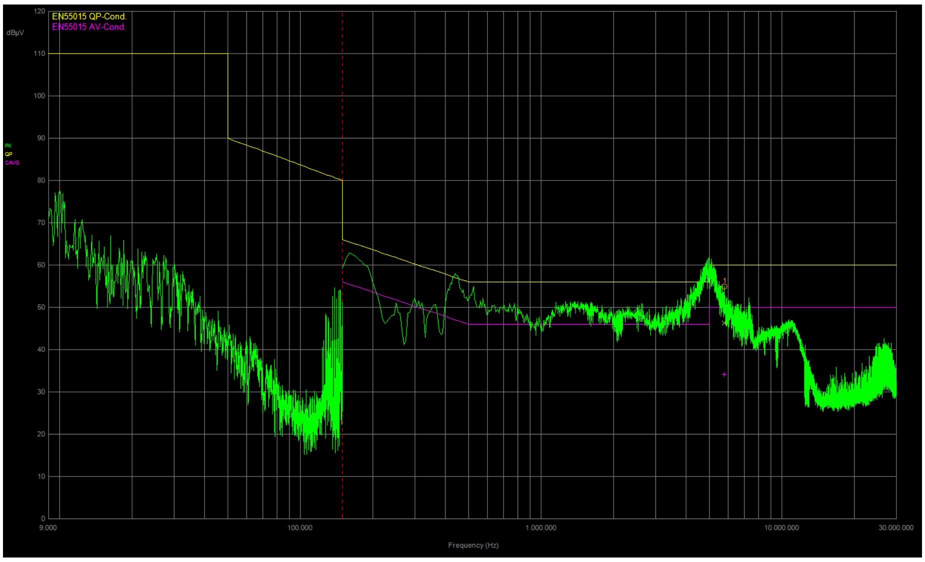


Figure 5-5: 9kHz-30MHz Line (test n 085)

1.31.2 9kHz-30MHz Neutral (test n 086)

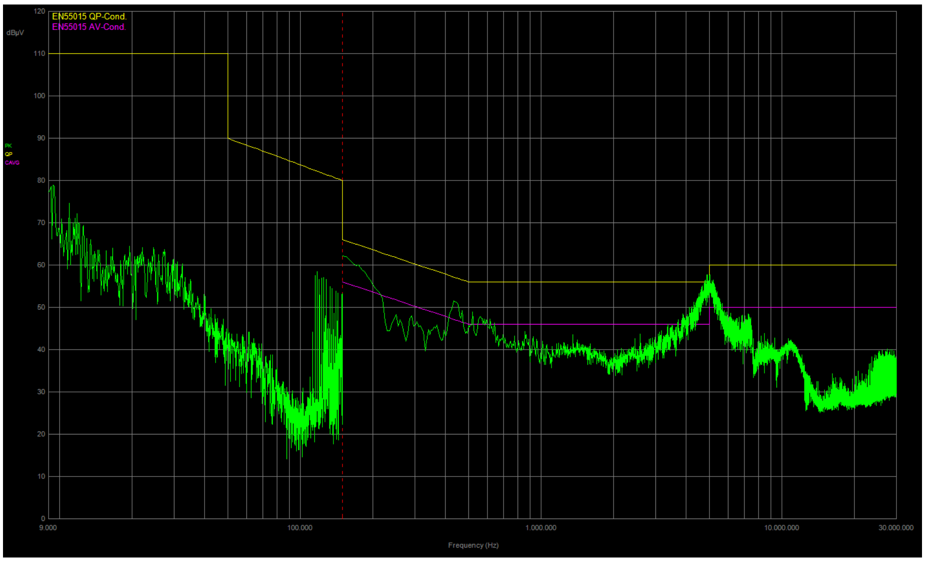


Figure 5-6: 9kHz-30MHz Neutral (test n 086)

1.31.3 150kHz-30MHz Line (test n 083)

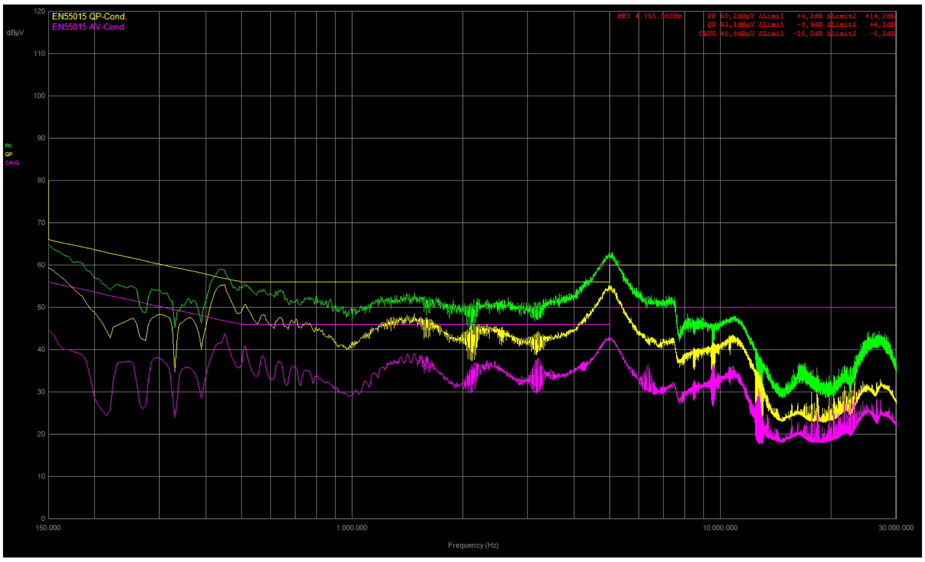


Figure 5-7: 150kHz-30MHz Line (test n 083)

1.31.4 150kHz-30MHz Neutral (test n 084)

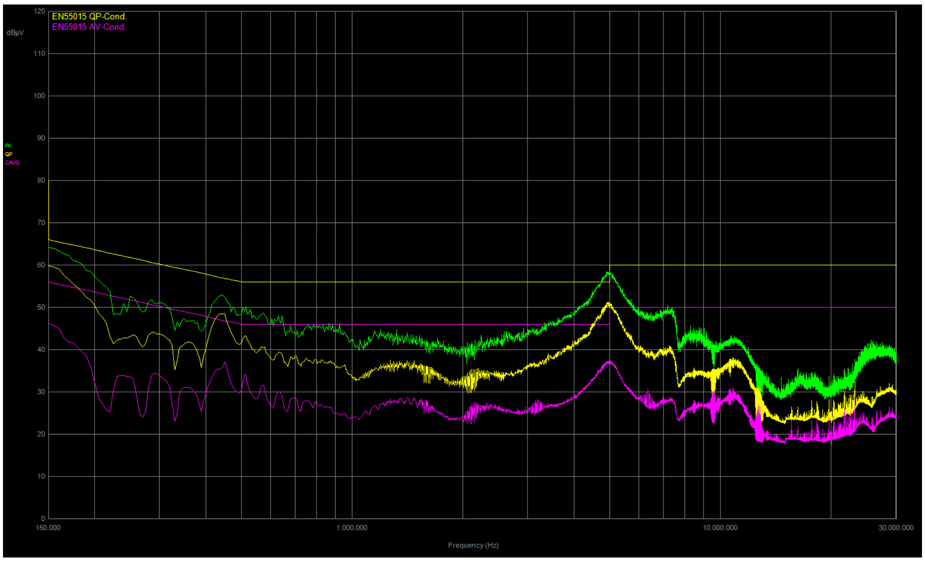


Figure 5-8: 150kHz-30MHz Neutral (test n 084)

6. References

[1] O. Jurchescu, "Conductivity measurements of organic materials using field-effect transistors (FETs) and space-charge-limited current (SCLC) technique," in *Handbook of Organic Materials for Optical and (Opto) Electronic Devices: Properties and Applications*, Elsevier Inc., 2013, pp. 377-397.

[2] D. Natali, "Fundamentals of organic electronic devices," in *Organic Flexible Electronics*, Elsevier, 2021, pp. 1-25.

[3] S. R. Puniredd, W. Pisula and K. Müllen, "Influence of film morphology on optical and electronic properties of organic materials," in *Handbook of Organic Materials for Optical and (Opto)Electronic Devices: Properties and Applications*, Elsevier Inc., 2013, pp. 83-101.

[4] "Organic solar cell - Wikipedia," [Online]. Available: https://en.wikipedia.org//wiki/Organic_solar_cell.

[5] J. Machiels, A. Verma, R. Appeltans, M. Buntinx, E. Ferraris and W. Deferme, "Printed Electronics (PE) As An enabling Technology to Realize Flexible Mass Customized Smart Applications," *Procedia CIRP,* vol. 96, pp. 115-120, January 2020.

[6] "Large-Scale Deposition of Organic Solar Cells | Ossila," [Online]. Available: https://www.ossila.com/pages/opv-large-scale-deposition. [Accessed 01 April 2021].

[7] S. Khan, L. Lorenzelli and R. S. Dahiya, "Technologies for printing sensors and electronics over large flexible substrates: A review," *IEEE Sensors,* vol. 15, no. 6, pp. 3164-3185.

[8] M. Hösel, "Large-scale Roll-to-Roll Fabrication of Organic Solar Cells for Energy Production," 2014.

[9] S. Khan, "Towards Merging of Microfabrication and Printing of Si μ-Wires for Flexible Electronics," February 2016.

[10] S. Fan, "Microstructured flexible sensors for wearable technologies," 2017.

[11] R. Søndergaard, M. Hösel, D. Angmo, T. T. Larsen-Olsen and F. C. Krebs, "Roll-to-roll fabrication of polymer solar cells," *Mater. Today,* vol. 15, no. 1-2, pp. 36-49.

[12] "Flexible Substrates and Barriers," in *Organic Solar cells*, Jenny Stanford Publishing, 2014, pp. 609-656.

[13] C. Brabec, U. Scherf and V. Dyakonov, Organic Photovoltaics, vol. 9783527332250, Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2014.

[14] P. Maury et al, "Roll-to-roll UV imprint lithography for flexible electronics," *Microelectron. Eng.,* vol. 88, no. 8, p. 2052–2055, 2011.

[15] "UV LED Curing Systems | LED UV Curing Devices," [Online]. Available: https://www.doctoruv.com/uv-curing-systems/uv-led-curing. [Accessed 01 April 2021].

[16] "UV LED curing lamps: benefits and best technologies," [Online]. Available: https://www.photoelcuring.com/en/technologies/uv-led/benefits-led-uv-curing-lamps/. [Accessed 01 April 2021].

[17] E. Kiyoi, "The State of UV-LED Curing : An Investigation of Chemistry and Applications," *RADTECH Rep,* vol. 2, no. 2, pp. 32-36, 2013.

[18] N. Haimerl, H. Runge and K. Hönle, "New UV/LED Curing Systems for Flexo and Digital Printing Chairman supervisory board: Press Release," 2019. [Online]. Available: www.hoenle.de. [Accessed 01 April 2021].

[19] "GEW UV | LeoLED Cassette," [Online]. Available: https://www.gewuv.com/products/led-uv-systems/leoled-cassette/. [Accessed 01 April 2021].